Getting Started with CapSense®

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1. Introduction

1.1 How to Use This Guide

This document is the starting point for any new CapSense® design. The most important thing the guide does is to help you to select the right device for your application using our CapSense Selector Guide in Chapter 5. In addition, using this guide you can:

- Become familiar with technology underlying CapSense solutions
- Understand important design considerations
- Migrate existing designs between CapSense devices
- Review the many resources available to support your entire design cycle

Once you are ready to design your application, consult the Design Guide specific to the CapSense device family you have selected.

1.2 Cypress CapSense® Products

Cypress CapSense solutions bring elegant, reliable, and easy-to-use touch sensing functionality to your design. Our capacitive touch sensing solutions have replaced more than 3.5 billion mechanical buttons. CapSense touch sensing has changed the face of industrial design in products such as cell phones, PCs, consumer electronics, automotive features and white goods. Cypress's robust CapSense solutions leverage our flexible Programmable System-on-Chip (PSoC®) architecture, which accelerates time-to-market, integrates critical system functions and reduces BOM costs.

1.2.1 Cypress CapSense Differentiation

- Robust sensing technology
- High noise immunity
- High performance across a variety of overlay materials and thickness.
- SmartSense™ Auto-Tuning technology
- Proximity sensing
- Water tolerant performance
- Complete user interface solution including audio, visual, and haptics feedback
- Low power consumption
- Wide operating voltage range (1.71 V to 5.5 V)
- Small form factor packaging
- Reduced BOM cost with integrated CapSense Plus features (ADC, DAC, LED, PWM)

1.3 Document Revision History

Revision	Issue Date	Origin of Change	Description of Change
**	12/17/2010	SSHH	New Guide
*A	3/4/2011	SSHH	Multiple chapter enhancements for content and reader clarity

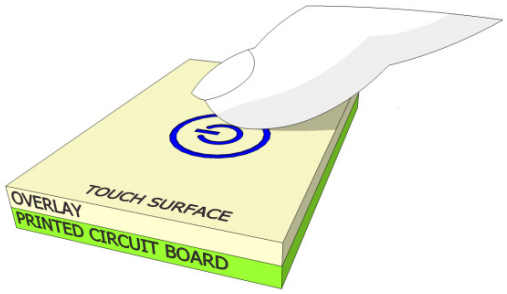
1.4 Document Conventions

Convention	Usage
`Courier New`	Displays file locations, user entered text, and source code: C:\ ...cd\icc\
Italics	Displays file names and reference documentation: Read about the *sourcefile.hex* file in the *PSoC Designer User Guide*.
[Bracketed, Bold]	Displays keyboard commands in procedures: [Enter] or [Ctrl] [C]
File > Open	Represents menu paths: File > Open > New Project
Bold	Displays commands, menu paths, and icon names in procedures: Click the **File** icon and then click **Open**.
Times New Roman	Displays an equation: 2 + 2 = 4
Text in gray boxes	Describes Cautions or unique functionality of the product.

2. CapSense Technology

Cypress's CapSense controllers use changes in capacitance to detect the presence of a finger on or near a touch surface, as shown in Figure 2-1. This capacitive sensor example illustrates a touch sensor replacement for a mechanical button. This sensing function is achieved using a combination of hardware and firmware. The following section provides an overview of capacitive sensing technology and CapSense solutions.

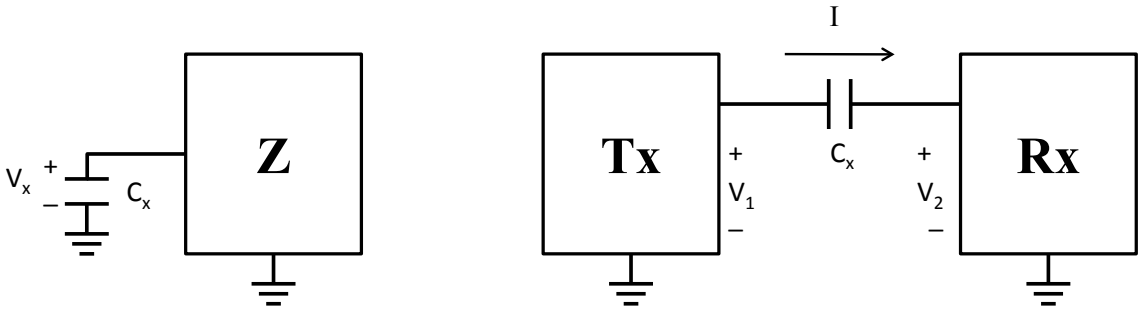
Figure 2-1. Illustration of a Capacitance Sensor Application



2.1 Capacitive Sensing Methods

Capacitance can be measured between two points using either self capacitance or mutual capacitance.

Figure 2-2. Self-Capacitance and Mutual-Capacitance Methods



2.1.1 Self Capacitance

Self capacitance uses a single pin and measures the capacitance between that pin and ground. A self-capacitance sensing system operates by driving current on a pin connected to a sensor and measuring the voltage. When a finger is placed on the sensor it increases the measured capacitance. The self-capacitance effect is best suited for single-touch sensors, such as buttons and sliders

Cypress's CapSense solutions use self-capacitance sensing. This approach makes more efficient use of pins for single touch sensors and sliders.

2.1.2 Mutual Capacitance

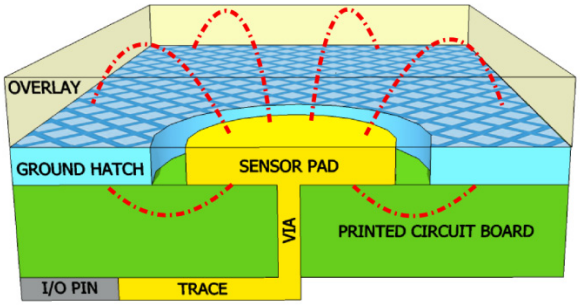
Mutual capacitance uses a pair of pins and measures the capacitance between those pins. A mutual-capacitance system operates by driving a current on a transmit pin and measuring the charge on a receive pin. When a finger is placed between the transmit and receive pins it decreases the measured capacitance. The mutual-capacitance effect is best suited to multitouch systems, such as touch screens and track pads.

Cypress's TrueTouch™ touchscreen solutions use mutual-capacitance sensing. Visit TrueTouch™ Touch Screen Controllers to learn about these products. Cypress also offers trackpad solutions. Contact your local Cypress sales office directly for more information. To find your local sales office click here.

2.2 Self-Capacitance Equivalent Model

In a CapSense self-capacitance system, the sensor capacitance measured by the controller is named C_X. When a finger is not on the sensor, C_X equals the parasitic capacitance of the system. This parasitic capacitance, C_P, is a simplification of the distributed capacitance that includes the effects of the sensor pad, the overlay, the trace between the CapSense controller pin and the sensor pad, the vias through the circuit board, and the pin capacitance of the CapSense controller. C_P is related to the electric field around the sensor pad. Although Figure 2-3 shows field lines only around the sensor pad, the actual electric field is more complicated.

Figure 2-3. C_P and Electric Field



When a finger touches the sensor surface, it forms a simple parallel plate capacitor with the sensor pad through the overlay. The result is called finger capacitance, C_F, and is defined by Equation 1. C_F is a simplification of a distributed capacitance that includes the effects of the human body and the return path to the circuit board ground.

$$C_F = \frac{\varepsilon_0 \varepsilon_r A}{D}$$ **Equation 1**

Where:

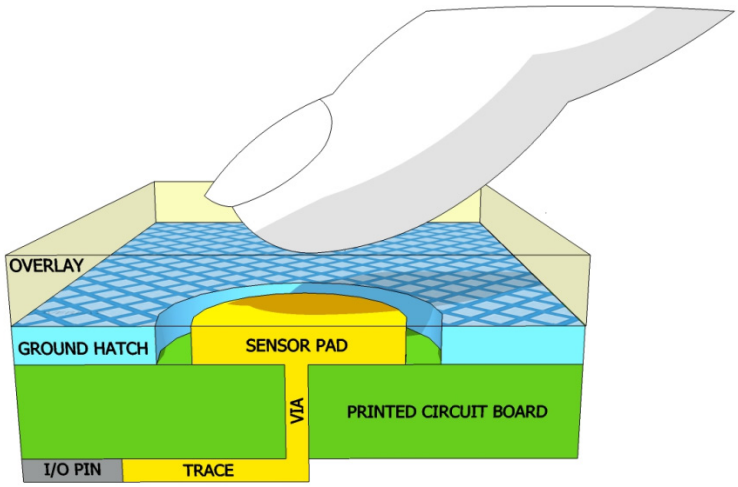
ε_0 = Free space permittivity

ε_r = Dielectric constant of overlay

A = Area of finger and sensor pad overlap

D = Overlay thickness

Figure 2-4. CapSense System Equivalent Model



With a finger on the sensor surface, C_X equals the sum of C_P and C_F.

$$C_X = C_P + C_F$$ **Equation 2**

2.3 CapSense Sensing Technology

2.3.1 Sensing Methods

There are a number of capacitive sensing methods currently in use across the electronics industry. Some of the major sensing methods include:

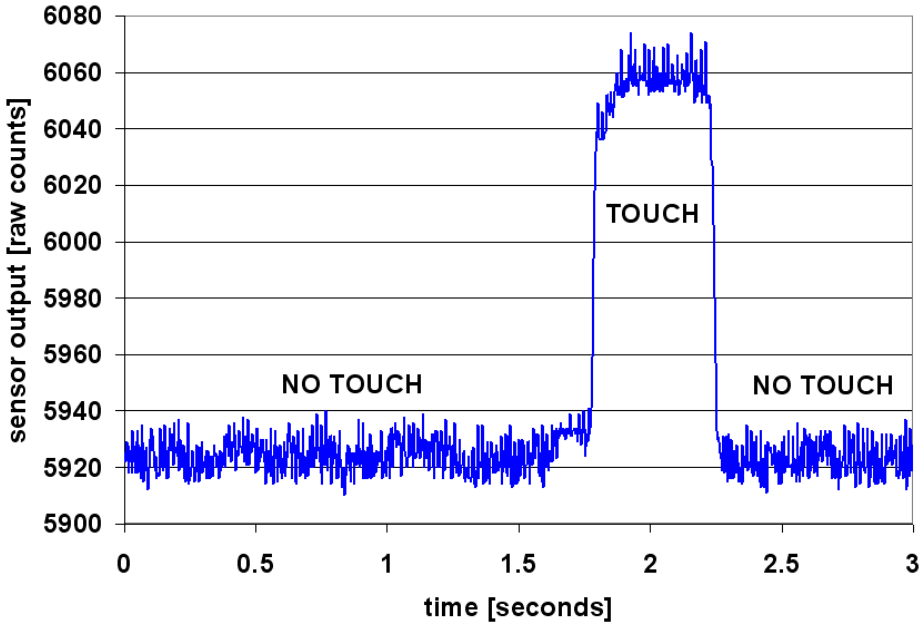
- *Charge Transfer*: Incremental packets of charge are transferred between the sensor capacitor and a reference capacitor until a reference voltage is reached. The number of charge transfers is used to track changes in sensor capacitance.
- *Relaxation Oscillator*: A sensor capacitor is used to directly set its frequency. An internal oscillator tracks the changes in frequency set by the sensor capacitor to detect the capacitance change caused by a finger.
- *TX-RX:* A source waveform is driven on the TX end of a mutual capacitance system and senses the response on the RX end. The received signal reflects changes in sensor capacitance.
- *ADC:* A current source generates a linear voltage ramp on a capacitor. This voltage is input to an analog comparator circuit. The comparator's output is monitored and a counter increments whenever it transitions from high to low.

Cypress CapSense devices measure sensor capacitance using either CapSense with Sigma Delta modulator (CSD), or CapSense Successive Approximation (CSA). Both methods are variants of the ADC method. The Electromagnetic Compatible variation of CSA (CSA_EMC) provides far superior noise immunity compared to the other sensing methods.

2.3.2 Capacitance Conversion

The CapSense algorithm converts the sensor capacitance into a digital count, called raw count. The raw count is interpreted as either a TOUCH or NO TOUCH state for the sensor. The numerical value of the raw count is the digital representation of the sensor capacitance, and increases as the capacitance increases. Sensitivity is a measure of how much the output will change for a given change on the input. The sensitivity of the CapSense sensor has units of counts-per-pF.

Figure 2-5. Output of Sensing Algorithm



2.3.3 CapSense with Sigma Delta Modulator (CSD)

Cypress's CSD method uses a switched capacitor circuit on the front end of the system to convert the sensor capacitance to an equivalent resistor, as shown in Equation 3. A Sigma-Delta modulator converts the current measured through the equivalent resistor into a digital count. When a finger is on the sensor, the capacitance increases and the equivalent resistance decreases. This causes an increase in the current through the resistor, resulting in an increase in the digital count.

The CSD method requires a single dedicated pin and a single external component, C_{mod}, or two dedicated pins and two external components, C_{mod} and R_B, depending on what CapSense part family is selected. Figure 2-6 shows the CSD configuration using two external components and two dedicated pins for the part family CY8C21x34

Figure 2-6. CSD Block Diagram

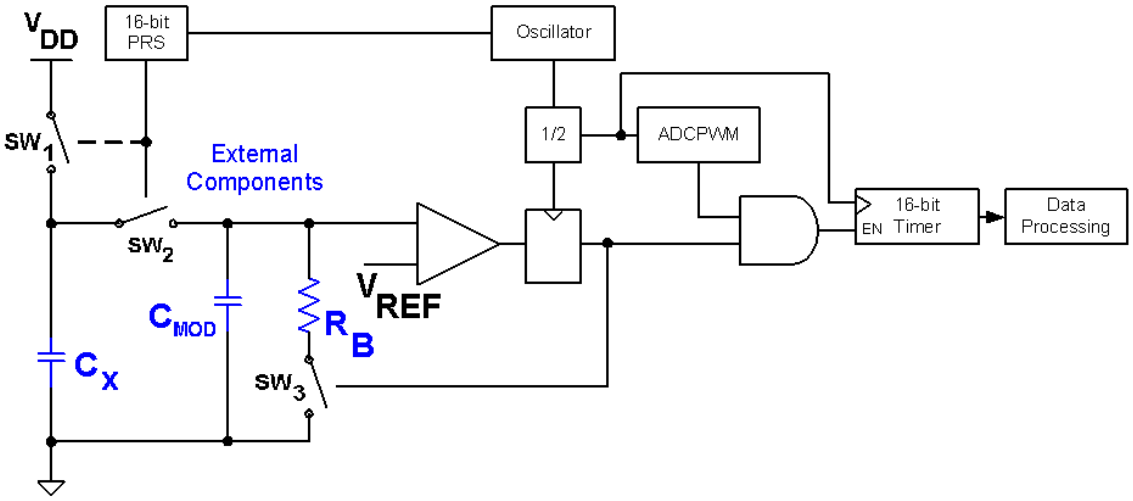
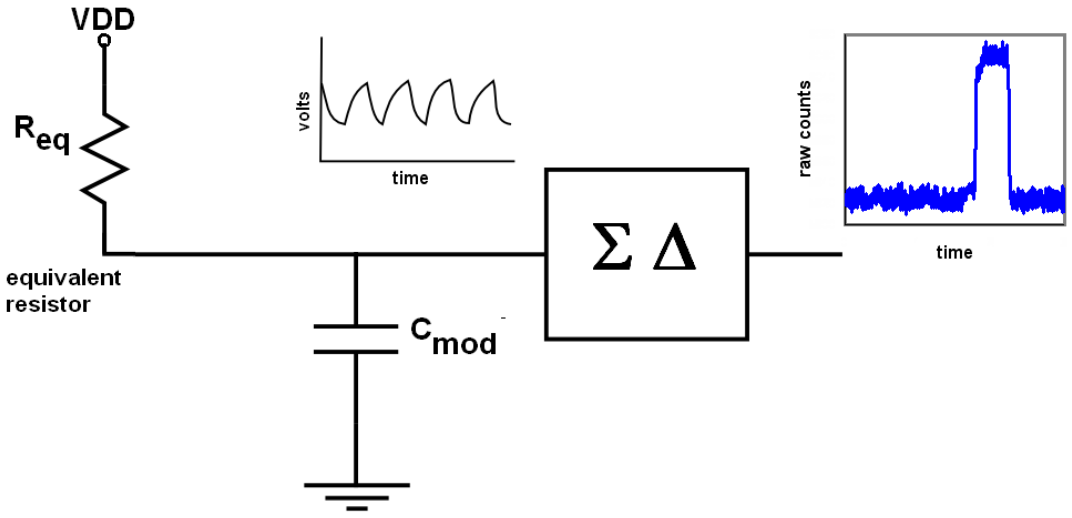


Figure 2-7. CSD Equivalent Circuit



$$R_{eq} = \frac{1}{f_{sw} \times C_P}$$ **Equation 3**

Where:

f_{SW} = switching frequency

C_P = sensor capacitance

For an in-depth discussion of Cypress's CSD sensing method refer to PSoC® CY8C20x66, CY8C20x66A, CY8C20x46/96, CY8C20x46A/96A, CY8C20x36, CY8C20x36A Technical Reference Manual (TRM).

2.3.4 CapSense Successive Approximation Electromagnetic Compatible (CSA_EMC)

Cypress's CSA_EMC method also uses a switched capacitor circuit on the front end of the system to convert the sensor capacitance to an equivalent resistor. An internal constant current source called the iDAC is calibrated with a successive approximation procedure until a preset voltage develops across the equivalent resistor. This baseline voltage is measured using a single slope ADC. When a finger is on the sensor the capacitance increases and the equivalent resistance decreases. This causes the voltage across the resistor to decrease and the ADC output increases. This results in an increase in the digital count.

The CSA_EMC method requires a single dedicated pin and a single external component, C_{mod}. This is an Integration capacitor that is used by the single slope ADC.

Figure 2-8. Block Diagram of CSA_EMC

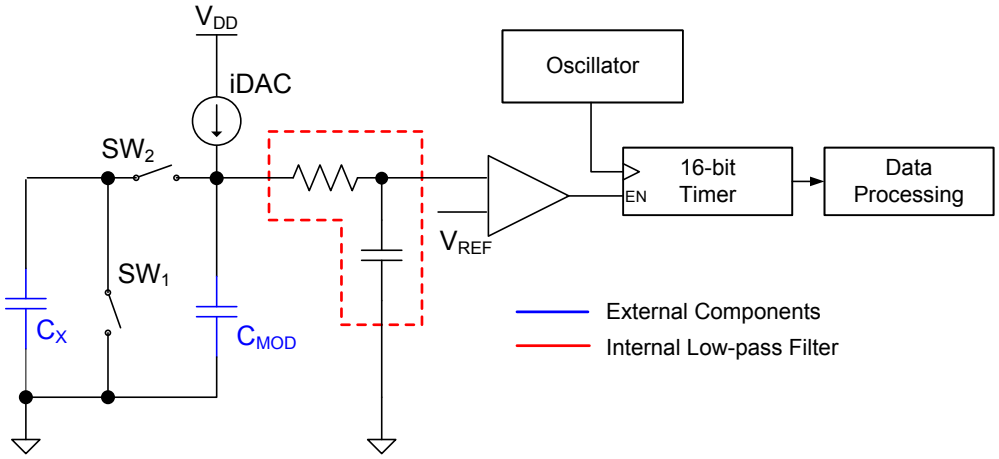
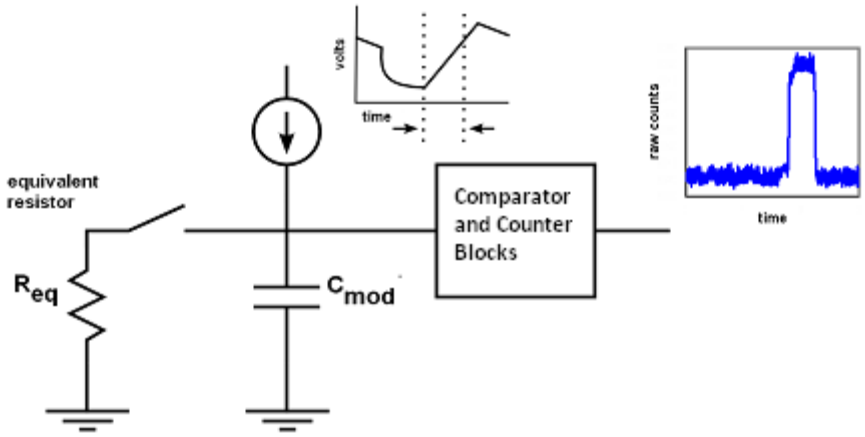


Figure 2-9. CSA_EMC Equivalent Circuit



The CSA_EMC CapSense algorithm has been enhanced to work well in the presence of RF interference. CSA_EMC is used in applications where CapSense is exposed to conducted interference, AC noise, and other noise sources such as inverters, transformers, and power supplies. Electromagnetic Compatibility (EMC) Considerations discusses this topic in detail.

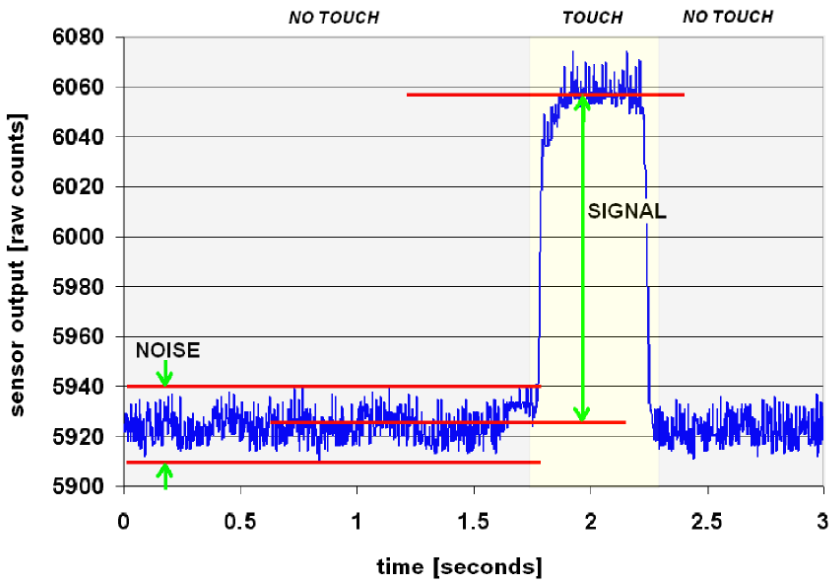
For an in-depth discussion of Cypress's CSA_EMC sensing method refer to PSoC® CY8C20x66, CY8C20x66A, CY8C20x46/96, CY8C20x46A/96A, CY8C20x36, CY8C20x36A Technical Reference Manual (TRM).

2.4 CapSense Tuning

Optimal CapSense system performance depends on board layout, button dimensions, overlay material and application requirements. These factors are discussed in Design Considerations. In addition to these factors, switching frequency and threshold levels must be carefully selected for robust and reliable performance. Tuning is the process of determining the optimum values for these parameters. Tuning is required to maintain high sensitivity to touch and to compensate for process variations in the sensor board, overlay material, and environmental conditions.

2.4.1 Signal-to-Noise Ratio (SNR)

Figure 2-10. Signal and Noise



One of the main goals of tuning a CapSense system is to reliably discriminate between TOUCH and NO TOUCH sensor states. The signal is the change in the sensor response when a finger is placed on the sensor. The change in the sensor response refers to a trend in the raw counts called the Baseline. This reference level is continuously updated when a finger is not on the sensor. For the signal-to-noise measurement, the Baseline reference level is the average raw count level with no finger present. For the purpose of signal-to-noise ratio calculation, the noise is the peak-to-peak variation in the sensor response when a finger is not present (internal noise). There is also noise present when a finger touches the sensor surface, but this is a combination of internal noise and noise injected via the finger. The noise introduced by the finger can affect the performance of the sensor, but, by definition, it is not part of the signal-to-noise ratio calculation. For reliable CapSense performance, signal strength needs to be significantly larger than noise. Figure 2-10 shows an example of signal and noise levels using real sensor data. In this example, the signal is a 135 count difference and the noise is a 27 count difference, so the signal-to-noise ratio (SNR) is 135:27, or 5:1.

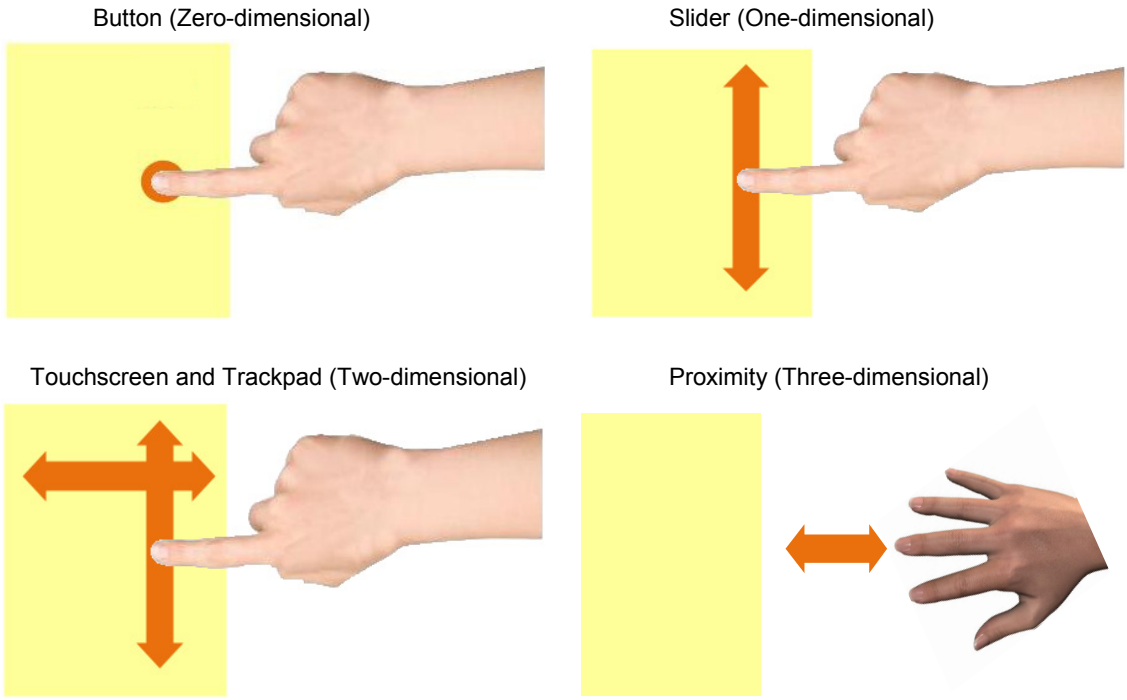
2.4.2 SmartSense™ Auto-Tuning

Tuning the touch sensing user interface is a critical step in ensuring proper system operation and a pleasant user experience. The typical design flow entails tuning the sensor interface in the initial design phase, during system integration, and finally production fine-tuning before the production ramp. Tuning is an iterative process and can be time consuming. SmartSense auto-tuning was developed to simplify the user interface development cycle. It is easy to use and significantly reduces the design cycle time by eliminating the tuning process throughout the entire product development cycle, from prototype to mass production. SmartSense tunes each CapSense sensor automatically at power up and then monitors and maintains optimum sensor performance during run time. This technology adapts for manufacturing variation in PCBs, overlays, and noise generators such as LCD inverters, AC line noise, and switch mode power supplies and automatically tunes them out. In systems with special requirements or very high C_P, auto-tuning may not be the ideal solution.

2.5 Sensor Types

Capacitive sensors can be broadly classified into four categories: buttons, sliders, touchscreens, and proximity sensors. Different sensor types cater to different market segments

Figure 2-11. Types of Capacitive Sensors



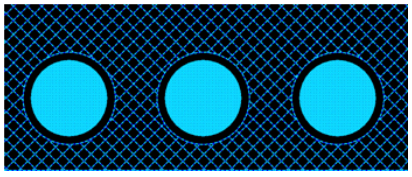
2.5.1 Buttons (Zero-dimensional Sensors)

CapSense buttons are used in a wide variety of applications including: home appliances, medical devices, TVs, monitors, audio systems, photo frames, notebooks, home security systems, white goods, industrial products, and lighting controls. Use CapSense buttons in place of mechanical buttons for higher reliability, lower cost, and more appealing industrial design.

2.5.1.1 Simple Buttons

The simplest capacitive sensor consists of a copper pad connected to a CapSense controller pin with a trace. A button is defined as the combination of the copper sensor pad and the nonconductive overlay material. The button is surrounded by grounded copper hatch separated by an annular gap. Each button requires one I/O pin of the CapSense controller.

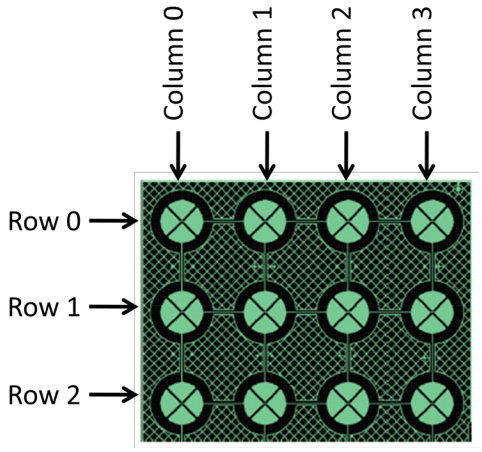
Figure 2-12. Typical Simple Buttons



2.5.1.2 Matrix Buttons

In applications requiring a high number of buttons such as a calculator keypad or a QWERTY keyboard, capacitive sensors can be arranged in a matrix. This allows a design to have more buttons than there are I/O pins on the CapSense controller.

Figure 2-13. Typical Matrix Buttons



A matrix button design consists of two groups of capacitive sensors: Row sensors and Column sensors. When a button is touched, it can be resolved by identifying the row and column sensors that are both in the TOUCH state. The number of buttons supported by the matrix is equal to the product of the number of rows and the number of columns.

$$Number\ of\ Matrix\ buttons = Number\ of\ Row\ sensors \times Number\ of\ column\ sensors$$ **Equation 4**

Using a matrix button design can result in a significant reduction in the number of I/O pins required. For example, the matrix in Figure 2-13 implements 12 buttons, but requires only seven I/O pins for sensors. An additional one or two dedicated pins need to be assigned to external components, depending on the sensing method selected.

Matrix buttons can only be sensed one at a time. When more than one row or column sensor is in the TOUCH state, then the finger location cannot be resolved, and the situation is considered an invalid condition. Some applications require multiple buttons to be sensed simultaneously, such as a keyboard with a Shift, Ctrl, and Alt key. In this case, the Shift, Ctrl and Alt keys should be designed as individual buttons, or should be changed to a mutual-capacitance sensor design.

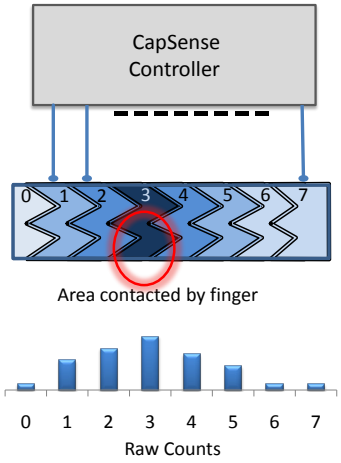
2.5.2 Sliders (One-dimensional Sensors)

Sliders are used for controls requiring gradual adjustments. Examples include a lighting control (dimmer), volume control, graphic equalizer, and speed control. A slider is built using an array of capacitive sensors called segments that are placed adjacent to one another. Actuation of one segment results in partial actuation of physically adjacent segments. By using an interpolation method called a centroid, you can achieve a higher resolution than the number of slider segments. In a typical application, a slider with five segments can resolve at least 100 physical finger positions on the slider. High resolution makes for smooth transitions in light or sound as a finger glides across a slider.

2.5.2.1 Linear Sliders

In a linear slider each CapSense controller I/O pin is connected to one slider segment. A zigzag pattern (double chevron) is recommended for slider segments. This layout ensures that when a segment is touched, the adjacent segments are also partially touched. Sensor data from multiple sensors improves the estimate of the finger position. The maximum number of slider segments is a function of the number of available CapSense controller pins and the required response time.

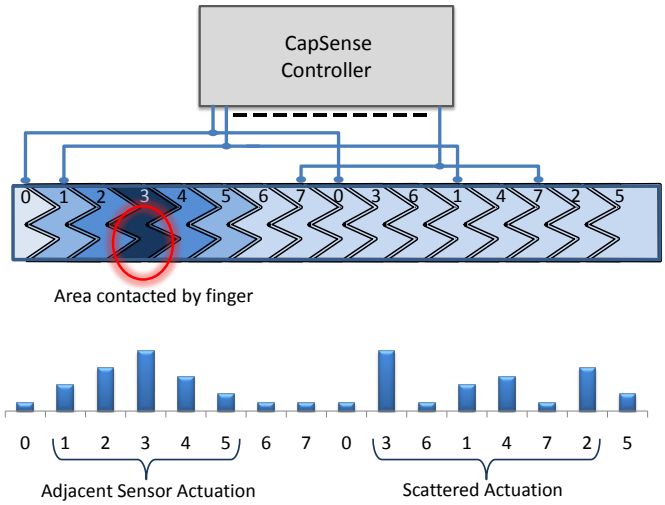
Figure 2-14. Linear Slider



2.5.2.2 Diplexed Sliders

In a diplexed slider each CapSense controller I/O pin is connected to two different slider segments. This allows a design to have twice as many slider segments as there are I/O pins. For example, a diplexed 16-segment slider requires only eight CapSense controller I/O pins.

Figure 2-15. 16-Segment Diplexed Slider

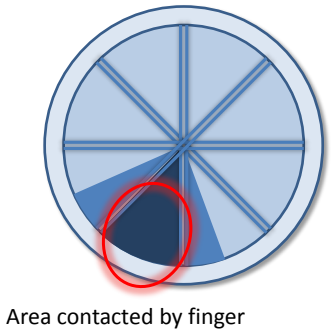

CapSense
Controller
0 1 2 3 4 5 6 7 0 3 6 1 4 7 2 5
Area contacted by finger
0 1 2 3 4 5 6 7 0 3 6 1 4 7 2 5
Adjacent Sensor Actuation
Scattered Actuation

For a diplexed slider to work properly the slider segments must be connected to the CapSense controller I/O pins in a pre-determined order. The first half of the segments are connected to the CapSense controller I/O pins sequentially (0, 1, 2 …7) and operate just like a linear slider. The second half of the segments are connected to the same CapSense controller I/O pins in a non-sequential order. This order exploits the fact that activation of one segment results in partial actuation of neighboring segments. While slider actuation of one half of the slider will result in aliasing onto the other half, the levels will be scattered in the untouched half. Sensing algorithms search for strong adjacent segment actuation and ignore scattered actuation in order to accurately determine finger position on the slider.

2.5.2.3 Radial Sliders

Radial sliders are similar to linear slider in that finger position is estimated using data from adjacent sensors, however, radial sliders are continuous (no beginning or end).

Figure 2-16. Radial Slider



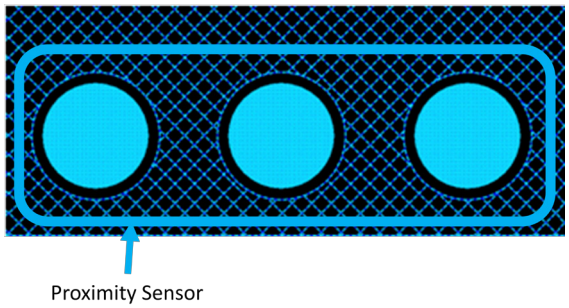
2.5.3 Touchscreens and Trackpads (Two-Dimensional Sensors)

Cypress's TrueTouch™ touchscreen solutions use mutual capacitance sensing. Visit TrueTouch™ Touch Screen Controllers to learn about these products. Cypress also offers trackpad solutions. Contact your local Cypress sales office directly for more information. To find your local sales office click here.

2.5.4 Proximity (Three-dimensional Sensors)

Proximity sensors detect the presence of a hand or other conductive object before it makes contact with the touch surface. Imagine a hand stretched out to operate a car audio system in the dark. The proximity sensor causes the buttons of the audio system to glow via backlight LEDs when the user's hand is near. One implementation of a proximity sensor consists of a long trace on the perimeter of user interface, as shown in Figure 2-17.

Figure 2-17. Proximity Sensor

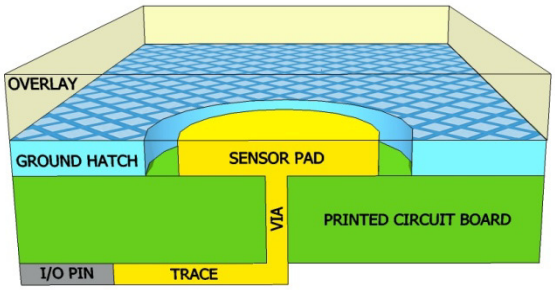


Another way to implement a proximity sensor is by ganging sensors together. This is accomplished by combining multiple sensor pads into one large sensor using firmware to connect the sensors from the internal analog multiplexer bus. Care must be taken not exceed the C_P limit for the sensing method when ganging sensors together.

2.6 Sensor Construction

2.6.1 Field Coupled via Copper Trace (PCB)

Figure 2-18. Field Coupled Using PCB

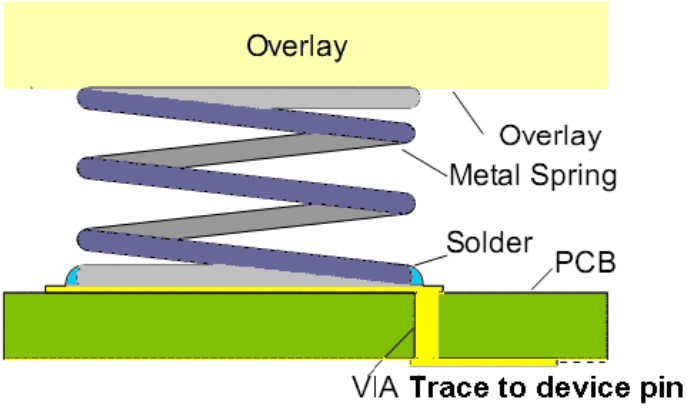


Features of a PCB-based design:

- Most common implementation
- Copper pads etched on the surface of the PCB act as sensor pads
- Electric field emanates from the copper sensor pad to ground plane
- No mechanical moving parts
- A nonconductive overlay serves as the touch surface for the button
- Ideal topology for simple flat panel designs
- Low BOM cost

2.6.2 Field Coupled via Spring/Gasket/Foam

Figure 2-19. Field Coupled via Spring



Features of a design based on springs/gaskets/foam:

- Electrical field coupled from PCB to overlay using a compressed spring, or conductive gasket or foam
- Conductive material itself acts as capacitive sensor pad
- No mechanical moving parts. Springs and foam do not move
- Coupled to touch sensor surface via nonconductive overlay
- Any conductive overlay serves as the button touch surface
- Ideal topology for curved, sloping or otherwise irregular front panels
- Ideal for designs where touch sensor surface is physically separated from silicon or mother board
- Ideal for designs where CapSense and mechanical button combination is desired

2.6.3 Field Coupled via Printed Ink

Features of a design based on printed ink:

- Electric field coupled with printed patterns on a flexible substrate using conductive ink
- High series resistance due to higher ohms-per-square of printed ink compared to copper
- High parasitic capacitance due to thin PCB
- No mechanical moving parts, but substrate is flexible
- Coupled to touch sensor surface with a nonconductive overlay
- Ideal topology for flexible front panels
- Flexible PCB can be one-layer or two-layer film

2.6.4 Field Coupled via ITO Film on Glass

Features of a design based on ITO film:

- Electric field coupled with printed or deposited patterns on glass
- Higher series resistance of ITO films compared to copper and printed ink
- No mechanical moving parts
- Ideal topology for graphical front panels

2.7 CapSense Feedback

Effective user interface designs include some type of feedback to the user when they are using the capacitive touch sense buttons. There are various forms of feedback, including visual, audio, and haptic (tactile). Depending on the user interface design multiple types of feedback can be used in combination.

2.7.1 Visual Feedback

LEDs and LCDs provide visual feedback to the user.

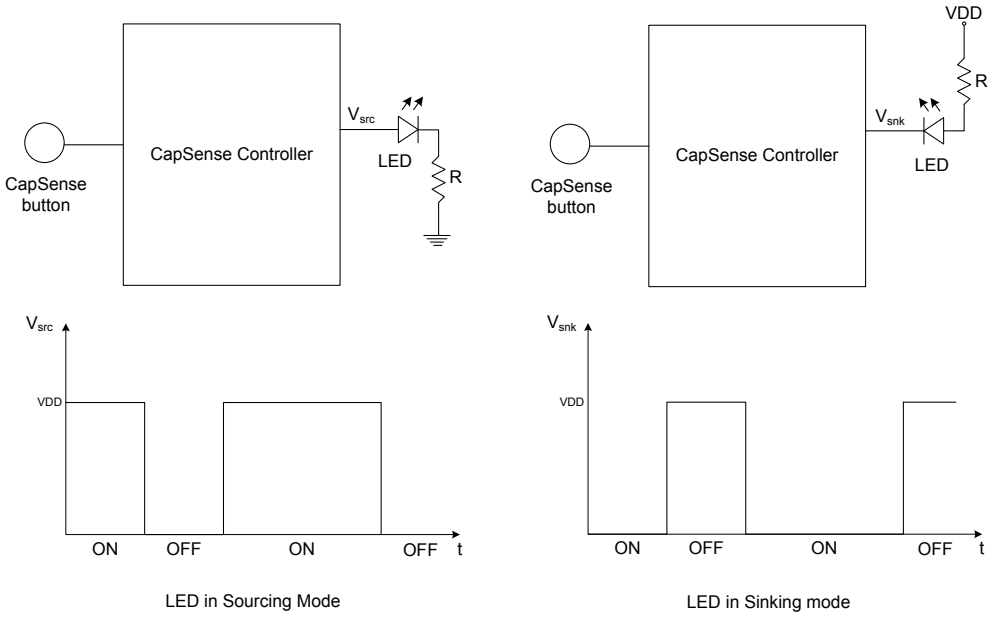
2.7.1.1 LED-based Visual Feedback

LEDs are used to indicate the status of buttons, sliders, and proximity sensors. LEDs can implement different effects when the sensor status changes.

2.7.1.1.1 LED ON/OFF

In visual feedback's simplest form, LEDs are turned ON or OFF in response to a finger touch. General-purpose I/Os are used to drive LEDs in either a sourcing or sinking configuration, as shown in Figure 2-20 on page 21.

Figure 2-20. LED Sourcing and Sinking Configuration



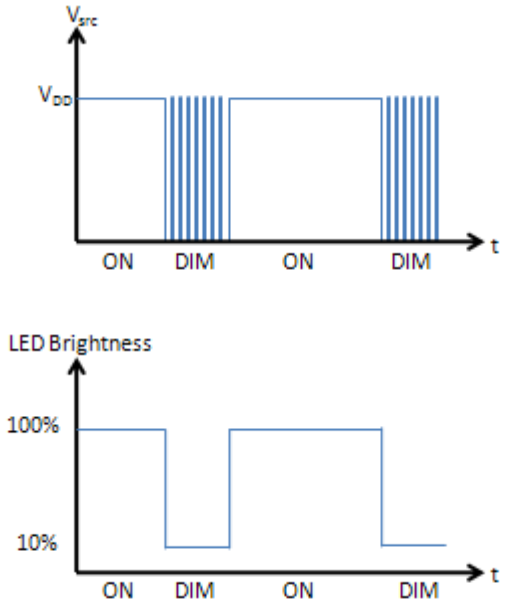
2.7.1.1.2 *Advanced LED Effects*

For user interfaces requiring more sophisticated visual effects a single hardware PWM or timer can be used to drive the LEDs. By varying the duty cycle of the PWM output you can achieve advanced effects such as variable LED brightness, fading, and breathing. A single hardware PWM or timer can be used to drive multiple LEDs, see AN13943 Multichannel LED Dimmer with CapSense Control for implementation details.

2.7.1.1.3 *LED Brightness*

By varying the duty cycle of the PWM output you can adjust the LED brightness as shown in Figure 2-21. This allows you to adjust your user interface brightness in response to ambient lighting conditions.

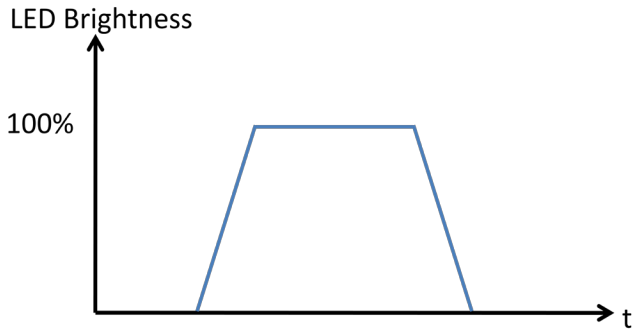
Figure 2-21. LED Brightness Control



2.7.1.1.4 LED Fading

By gradually changing the duty cycle between LED states you can achieve a fading effect as shown in Figure 2-22. For example, The LED appears to “fade in” (from OFF to ON) when the duty cycle is increased in a series of small steps.

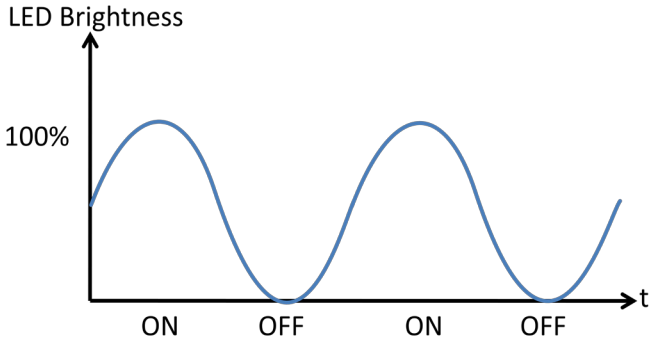
Figure 2-22. LED Fading



2.7.1.1.5 LED Breathing

Gradually increasing and decreasing the duty cycle between two levels on a continuous basis makes the LED appear to “breathe” as shown in Figure 2-23. LED breathing is useful when a system is in idle or stand-by mode. For example, a power button can appear to breathe to alert the user that it is active and can be operated.

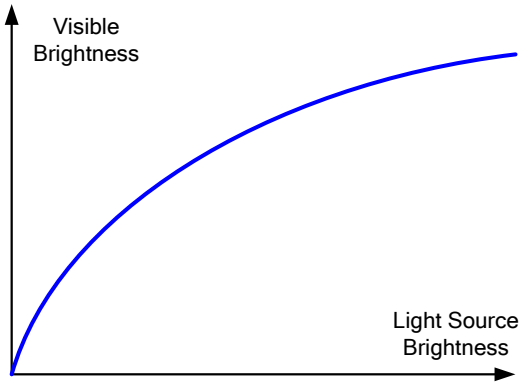
Figure 2-23. LED Breathing



Human Eye Sensitivity

The human eye’s sensitivity to the brightness of a light source looks similar to a logarithmic function (Figure 2-24). To provide a visible linear brightness change, the PWM duty cycle should be changed in an exponential way.

Figure 2-24. Human Eye Brightness Perception versus LED Luminous Flux



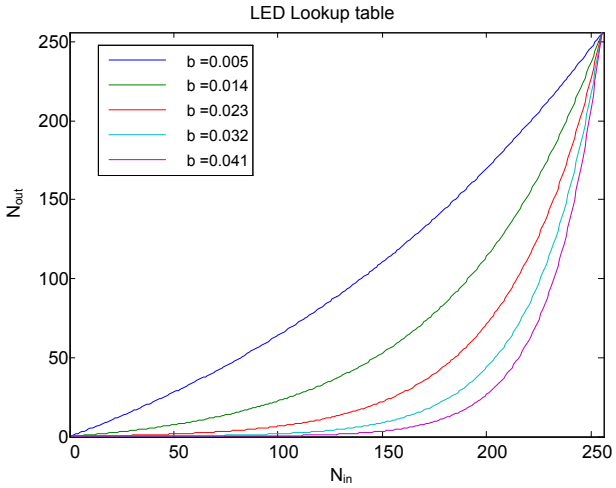
The linear brightness levels are transferred to exponential duty cycle values using the lookup table. The following expression is used for the conversion:

$$N_{out} = A(exp(N_{in} \cdot b) - 1); \qquad \textbf{Equation 5}$$

$$A = \frac{N_{max}}{\exp(N_{max} \cdot b) - 1}; \qquad \textbf{Equation 6}$$

Figure 2-25 illustrates the table graphs at different values of parameter *b*. Note that N_{max} is set to 255. This expression converts an 8-bit unsigned BYTE value to the same range. In Figure 2-25, you can easily see that the transfer characteristic becomes more exponential as the *b* parameter increases.

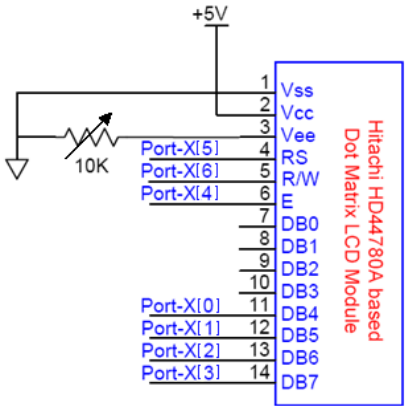
Figure 2-25. LED Duty Cycle Conversion Table



2.7.1.2 LCD-based Visual Feedback

LCDs provide visual feedback for CapSense buttons and sliders. The main advantage of using an LCD is that it can provide more information along with the feedback for each button press event. PSoC has built-in user modules for driving Hitachi HD44780A LCD module. This user module supports high level and low level APIs that can directly display data on the screen with ease. The typical connection for using the Hitachi HD44780A LCD module is shown in Figure 2-26.

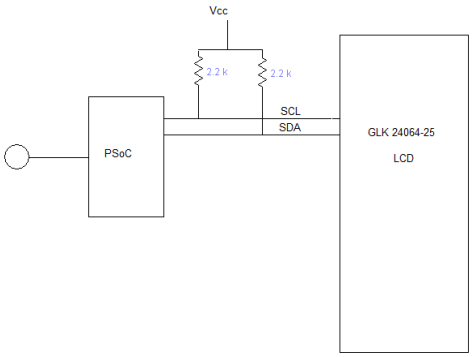
Figure 2-26. Hitachi Dot Matrix LCD Pin Connections



PSoC can also control LCDs through I^2C. The I^2CHW user module available in PSoC controls the GLK 24064-25 WB graphics LCD. Sending the commands through the I^2C bus is simplified. The CSD user module is configured to scan a set of buttons and any button press event initiates an I^2C transfer from the PSoC to the LCD as a feedback.

The typical circuit diagram for driving the GLK 24064-25 WB graphics LCD follows.

Figure 2-27. Implementing LCD Feedback with CapSense using PSoC



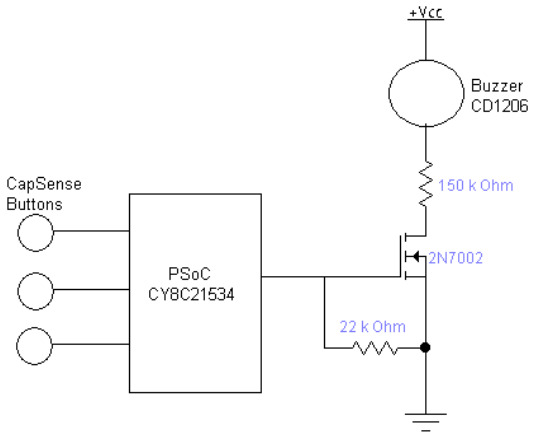
2.7.2 Haptic Feedback

Haptic, or tactile, feedback uses vibration to let the user know that a finger touch has been detected by the system. Vibrations are created by an actuator (DC motor) with Eccentric Rotating Mass (ERM). By using a PWM and a timer in the CapSense controller, different kinds of tactile feedback can be generated.

2.7.3 Audible Feedback

Audible feedback for CapSense buttons is implemented using a buzzer. The Pulse Width Modulator (PWM) can be used to output the PWM signal required for driving the buzzer as specified in the buzzer data sheet. The PWM user module available in PSoC is used for this purpose. PSoC can implement CapSense through its CSA and CSD algorithms. This application note describes CSD implementation. The CSD user module is configured to scan a set of buttons and sliders. When a button press event occurs, the feedback is provided by driving the buzzer at a particular intensity level. The circuit diagram for implementing the buzzer feedback follows.

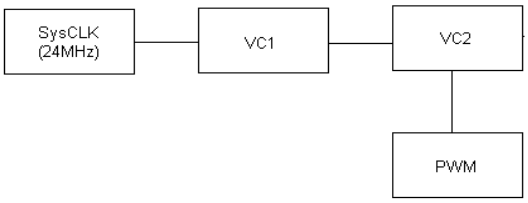
Figure 2-28. Implementing Audible Feedback for CapSense in PSoC



2.7.3.1 CapSense with Audible Feedback Configuration

Select CSD and PWM8 user module from the User Module list. Set the parameters for the CSD user module as shown in Table 2-1 on page 25. Calculate the PWM user module parameters based on the buzzer's resonant frequency. For example, consider the buzzer CD1206 with a resonant frequency of 2.4 kHz. A 2.4-kHz PWM signal with a 50-percent duty cycle is required to drive the buzzer to produce proper audio feedback.

Figure 2-29. PWM Clock Divider Calculation



To calculate the clock dividers to obtain a 2.4-kHz PWM output, see Figure 2-29. The System clock is set to 24 MHz. The required PWM output frequency is 2.4 kHz. Hence,

$$SysCLK/\ (N1 * N2 * \ (PeriodValue\ +\ 1)\ )\ = 2.4\ kHz \qquad \textbf{Equation 7}$$

Where, N1 and N2 are the VC1 and VC2 clock divider values respectively. Period Value is the value of period register input to the PWM.

That means:

$$24\ MHz\ /(N1 * N2 * \ (PeriodValue\ +\ 1)\ )\ = 2.4\ kHz \qquad \textbf{Equation 8}$$

Rearranging the equation we get:

$$N1 * N2 * (PeriodValue + 1) = 10000 \qquad \textbf{Equation 9}$$

The above equation has various integral solutions. For simplicity, this example will use N1 = 4 and N2 = 10. Substituting these values in the above equation we get

$$PeriodValue + 1 = 10000(4\ * 10) \equiv 250 \qquad \textbf{Equation 10}$$

Thus, Period Value is 249. To have a 50-percent duty cycle, the Compare value for the PWM is set as

$$(PeriodValue + 1)/2 = (249 + 1)/2\ \equiv 125 \qquad \textbf{Equation 11}$$

User Module parameters are matched as shown in the following table.

Table 2-1. PWM8 User Module Parameters

Parameter	Value
Name	PWM
Configuration	8 bit
Clock	VC2
Period	249
Pulse Width	125
Compare Type	Less than
Interrupt Type	Compare True
Clock Sync	Sync to SysClk

Note that the CSD user module automatically varies the clock dividers based on scan speed and resolution settings of the CSD user module. Therefore, re-enter the clock dividers every time the PWM module is invoked by writing the values directly to the configuration register OSC_CR1.The details about the Configuration register OSC_CR1 is present in the Technical Reference Manual.

The clock dividers VC1, VC2, and VC3 vary with the CSD scan speed and resolution as shown in Table 2-2 and Table 2-3 on page 26.

Table 2-2. Scan Speed versus VC1 Divider

Scanning Speed	VC1
Ultra fast	1
Fast	2
Normal	4
Slow	8

Table 2-3. Resolution versus VC1 and VC2 Clock Dividers

Resolution Bits	VC2	VC3
9	8	16
10	8	32
11	8	64
12	8	128
13	8	256
14	8	256
15	8	256
16	8	256

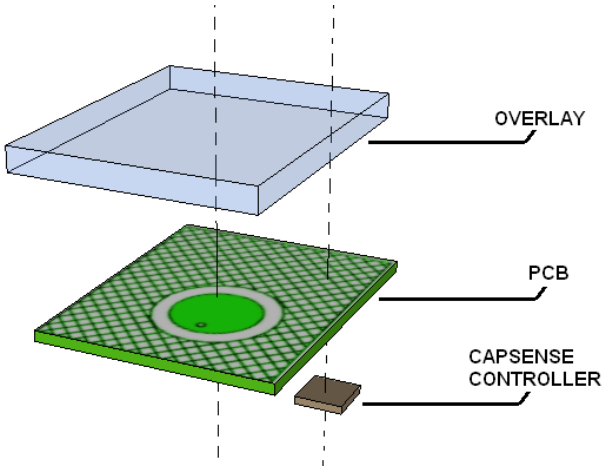
2.8 CapSense System Overview

CapSense solutions include not only the CapSense devices, but the entire environment in which they operate.

2.8.1 Hardware Component

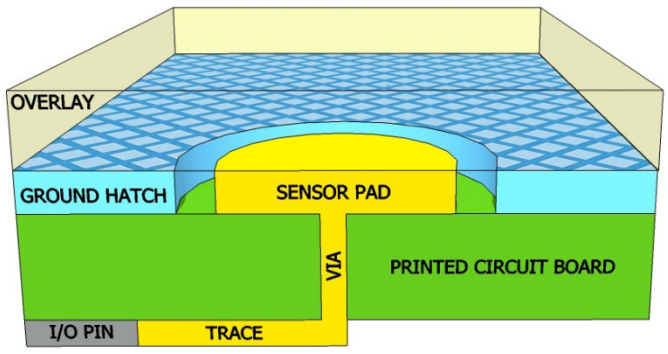
The CapSense controller resides within a larger system composed of a specially printed circuit board (PCB), and a touch-surface called the overlay that protects the PCB.

Figure 2-30. Exploded View of the CapSense Hardware



The capacitive sensor pads of a sensor board are formed by the PCB traces. The most common PCB format is a two-layer board with sensor pads and a hatched ground plane on the top, and the electrical components on the bottom. The electrical components include the CapSense controller and associated parts that convert the sensor capacitance into digital counts. A cross-sectional view of a two-layer board stack-up is shown in Figure 2-31.

Figure 2-31. Two-Layer Stack Up of a CapSense Board



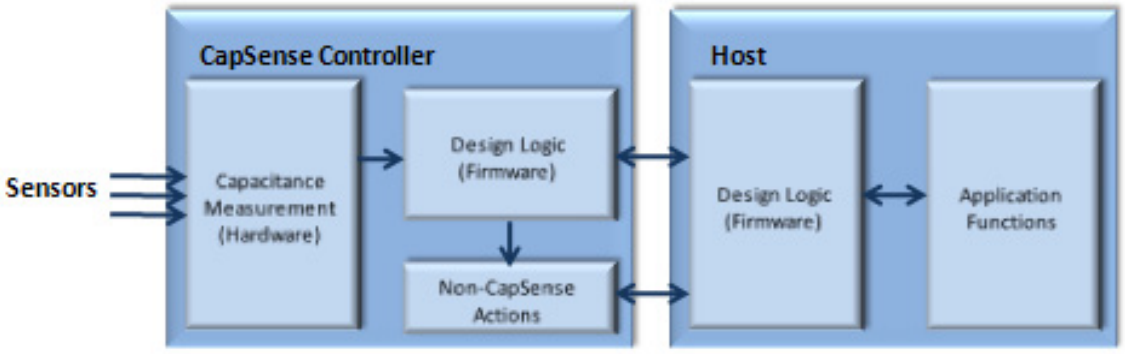
Four-layer designs are an option when board area must be minimized. PCB layout plays a very important role in CapSense system performance. Best practices are discussed in Design Considerations.

2.8.2 Firmware Component

Firmware is a vital component of the CapSense system that processes the raw count data and makes logical decisions. The amount of firmware development required for your application depends on which CapSense device you select.

Devices from the CapSense Express family are fully configurable and do not require any firmware development on the CapSense controller itself. These devices are appropriate for systems where the finger touch data is sent to a host for higher level processing. Such a system is shown in Figure 2-32.

Figure 2-32. Example CapSense Express System Implementation



Devices from the CapSense and CapSense Plus families are fully programmable. These devices allow complex system level integration. These controllers can process the raw count data as well as perform other system functions.

See the CapSense Product Portfolio and Selector Guide for additional details. Cypress's PSoC Designer™ accommodates firmware development in C and assembly language. Refer to Resources for more information on this and other tools.

3. Design Considerations

When designing capacitive touch sense technology into your application it is crucial to keep in mind that the CapSense device exists within a larger framework. Careful attention to every level of detail from PCB layout to user interface to end-use operating environment leads to robust and reliable system performance.

3.1 Overlay Selection

In a CapSense design, overlay material is placed over the sensor pad to protect it from the environment and prevent direct finger contact.

3.1.1 Relationship to CapSense Signal Strength

In the Self-Capacitance Equivalent Model section, Equation 1 was presented for finger capacitance.

$$C_F = \frac{\varepsilon_0 \varepsilon_r A}{D}$$

Where:

ε_0 = Free space permittivity

ε_r = Dielectric constant of overlay

A = Area of finger and sensor pad overlap

D = Overlay thickness

To increase the CapSense signal, choose an overlay material with higher dielectric constant, decrease the overlay thickness, and increase the button diameter.

Table 3-1. Overlay Material Dielectric Strength

Material	Breakdown Voltage (V/mm)	Min. Overlay Thickness at 12 kV (mm)
Air	1200–2800	10
Wood – dry	3900	3
Glass – common	7900	1.5
Glass – Borosilicate (Pyrex®)	13,000	0.9
PMMA Plastic (Plexiglas®)	13,000	0.9
ABS	16,000	0.8
Polycarbonate (Lexan®)	16,000	0.8
Formica	18,000	0.7
FR-4	28,000	0.4
PET Film (Mylar®)	280,000	0.04
Polymide film (Kapton®)	290,000	0.04

Conductive material cannot be used as an overlay because it interferes with the electric field pattern. For this reason, do not use paints that contain metal particles in the overlay.

3.1.2 Bonding Overlay to PCB

Since the dielectric constant of air is very low, an air gap between the overlay and sensor degrades the performance of the sensor. To eliminate the air gap, an adhesive is typically used to bond the overlay to the CapSense PCB. The adhesive must be nonconductive. A transparent acrylic adhesive film from 3M™ called 200MP is qualified for use in CapSense applications. This special adhesive is dispensed from paper-backed tape rolls (3M™ product numbers 467MP and 468MP).

3.2 ESD Protection

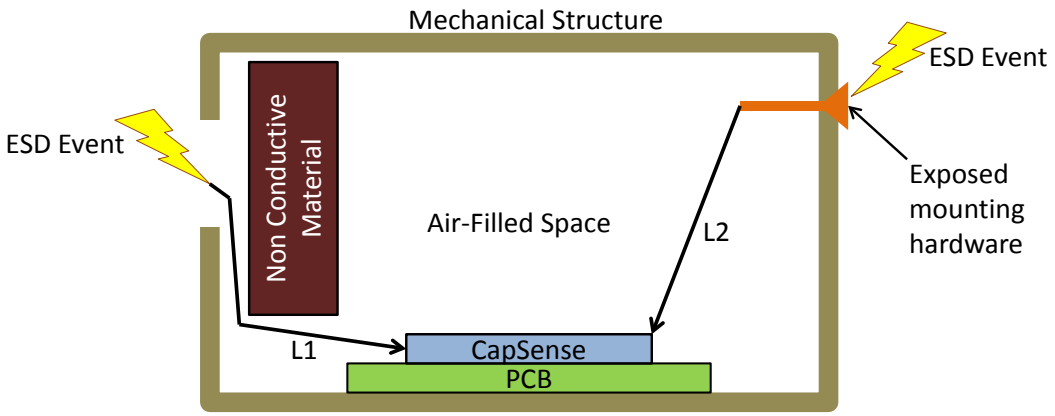
Robust ESD tolerance is a natural byproduct of thoughtful system design. By considering how contact discharge will occur in your end product, particularly in your user interface, it is possible to withstand an 18 kV discharge event without incurring any damage to the CapSense controller.

CapSense controller pins can withstand a direct 2-kV event. In most cases, the overlay material provides sufficient ESD protection for the controller pins. Table 3-1 on page 29 lists the thickness of various overlay materials required to protect the CapSense sensors from a 12-kV discharge as specified in IEC 61000-4-2. If the overlay material does not provide sufficient protection, ESD countermeasures should be applied in the following order: Prevent, Redirect, Clamp.

3.2.1 Preventing ESD Discharge

Preventing the ESD discharge from reaching the CapSense controller is the best countermeasure you can take. Make certain that all paths on the touch surface have a breakdown voltage greater than any voltage to which the surface may be exposed. Also, design your system to maintain an appropriate distance between the CapSense controller and possible sources of ESD. In the example illustrated in Figure 3-1, if L1 and L2 are greater than 10 mm the system will withstand 12 kV.

Figure 3-1. ESD Path

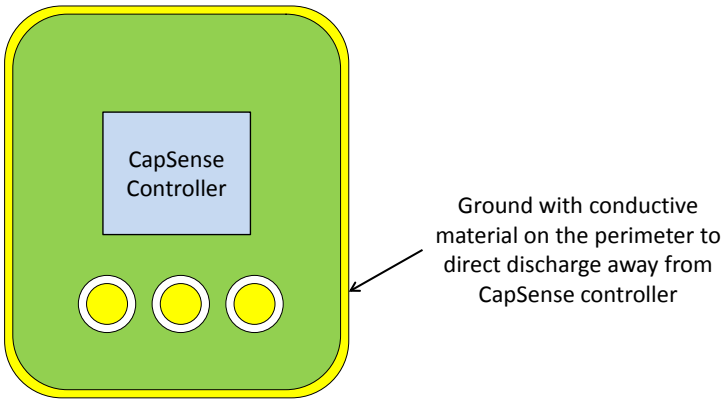


If it is not possible to maintain adequate distance, place a protective layer of a high breakdown voltage material between the ESD source and CapSense controller. One layer of 5 mil-thick Kapton® tape will withstand 18 kV. Refer to Table 3-1 on page 29 for other material dielectric strengths.

3.2.2 Redirect

If your product is densely packed, it may not be possible to prevent the discharge event. In this case you can protect the CapSense controller by controlling where the discharge occurs. This can be achieved through a combination of PCB layout, mechanical layout of the system, and conductive tape or other shielding material. A standard practice is to place a guard ring on the perimeter of the circuit board. The guard ring should connect to chassis ground.

Figure 3-2. Guard Ring

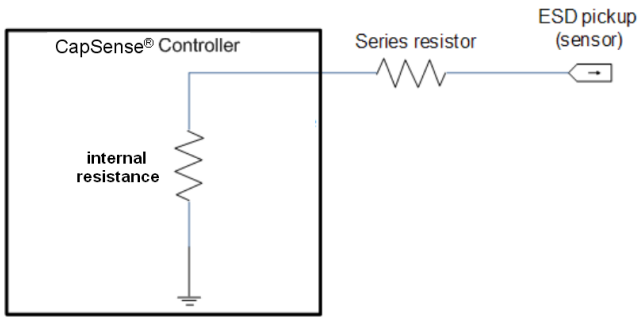


As recommended in PCB Layout Guidelines, providing a hatched ground plane around the button or slider sensor can also redirect the ESD event away from the sensor and CapSense controller.

3.2.3 Clamp

Because CapSense sensors are purposely placed in close proximity to the touch surface, it may not be practical to redirect the discharge path. In this case including series resistors or special purpose ESD protection devices may be appropriate. Adding a series resistor on the vulnerable traces is a cost effective protection method. This technique works by splitting the dissipation between the resistor and the controller. The recommended series resistance added to the CapSense inputs is 560 ohms. More details can be found in the Series Resistor section.

Figure 3-3. ESD Protection Using a Series Resistor



A more effective method is to provide special purpose ESD protection devices on the vulnerable traces. ESD protection devices for CapSense need to be low capacitance. Table 3-2 lists devices recommended for use with CapSense controllers.

Table 3-2. ESD Protection Devices

ESD Protection device		Input Capacitance	Leakage Current	Contact Discharge maximum limit	Air Discharge maximum limit
Manufacturer	Part Number				
Littlefuse	SP723	5 pF	2 nA	8 kV	15 kV
Vishay	VBUS05L1-DD1	0.3 pF	0.1 µA <	+/-15 kV	+/-16 kV
NXP	NUP1301	0.75 pF	30 nA	8 kV	15 kV

3.3 Electromagnetic Compatibility (EMC) Considerations

EMC is concerned with the generation, transmission, and reception of electromagnetic energy that can upset the working of a system. The source (emitter) produces the emission, and a transfer or coupling path transfers the emission energy to a receptor, where it is processed, resulting in either desired or undesired behavior. Many electronic devices are required to comply with specific limits for emitted energy and susceptibility to external upsets. There are several regulatory bodies worldwide that set regional regulations to help ensure that electronic devices do not interfere with each other. These regulations help prevent your computer from interfering with your television, or worse, a hospital X-ray machine or ventilator, or corrupting the operation of a critical medical monitor.

CMOS analog and digital circuits have very high input impedance. As a result, they are quite sensitive to external electric fields. Suitable precautions must be taken to ensure their proper operation in the presence of radiated and conducted noise.

3.3.1 Radiated Interference

Radiated electrical energy can influence system measurements and potentially influence the operation of the CapSense processor core. The interference enters the CapSense chip at the PCB level, through the sensor traces, and via other digital and analog inputs.

Layout guidelines for minimizing the effects of RF interference are discussed in the following sections.

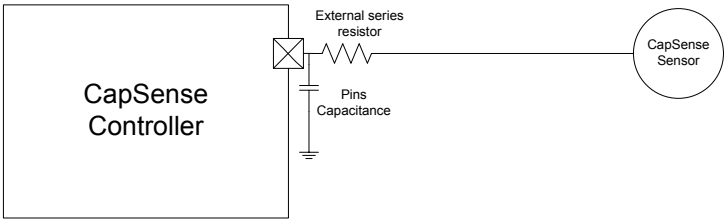
3.3.1.1 Ground Plane

In general, providing a ground plane on the PCB helps to reduce the RF noise picked up by the CapSense controller.

3.3.1.2 Series Resistor

Every CapSense controller pin has some parasitic capacitance, C_P, associated with it. Adding an external resistor forms a low pass RC filter that can dampen RF noise amplitude.

Figure 3-4. RC Filter



Series resistors should be placed within 10 mm of the CapSense controller pins.

3.3.1.2.1 CapSense Input Lines

The recommended series resistance for CapSense input lines is 560 ohms. Adding resistance changes the time constant of the switched capacitor circuit that converts C_P into an equivalent resistor. If the value is set larger than 560 ohms, the slower time constant of the switching circuit limits the amount of charge that can transfer, and this lowers the signal level, which in turn lowers SNR. Smaller values are better, but are less effective at blocking RF.

3.3.1.2.2 Digital Communication Lines

Communication lines, such as I^2C, and SPI, also benefit from series resistance. 330 ohms is recommended for communication lines. Communication lines have long traces that act as antennae like the CapSense traces. If more than 330 ohms is placed in series on these lines, the voltage levels fall out of spec with the worst case combination of supply voltages between systems and the input impedance of the receiver.

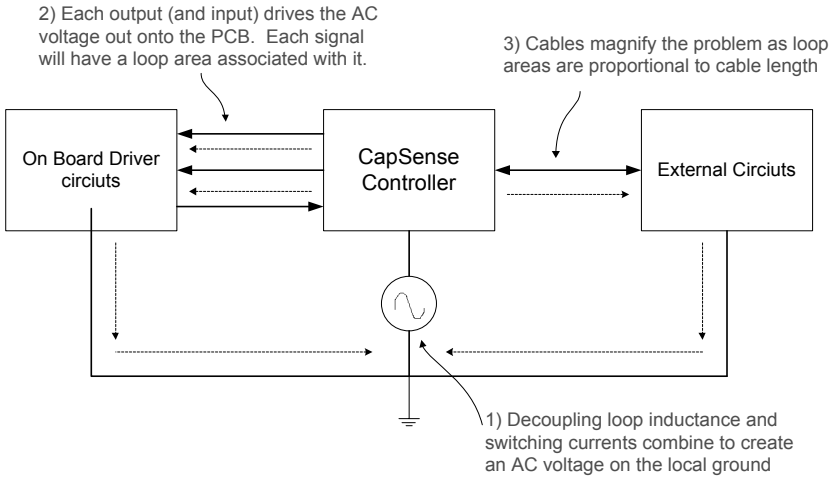
3.3.1.3 Trace Length

Long traces can pick up more noise than short traces. Long traces also add to C_P. Minimize trace length whenever possible.

3.3.1.4 Current Loop Area

Another important layout consideration is to minimize the return path for current. General system emission suppression techniques include adding a decoupling capacitor network, and reducing current loops. Current loops create issues for both emission and immunity. A proper ground plane scheme can make a big reduction in path length. Hatched ground instead of solid fill should be provided near the sensors or traces to reduce the impact of parasitic capacitance. A solid ground flood is not recommended within 1 cm of CapSense sensors or traces due to an increase the parasitic capacitance. Figure 3-5 shows an example of an improper grounding scheme. The layout would greatly improve by reducing the loop area.

Figure 3-5. Improper Ground Scheme and Ground Loop


2) Each output (and input) drives the AC voltage out onto the PCB. Each signal will have a loop area associated with it.
3) Cables magnify the problem as loop areas are proportional to cable length
On Board Driver circuits
CapSense Controller
External Circiuts
1) Decoupling loop inductance and switching currents combine to create an AC voltage on the local ground

In Figure 3-6, two sensors are surrounded by a ground plane that is connected to CapSense controller ground, while a third sensor is surrounded by ground which is connected to the other ground plane through the long traces of other circuitry. This creates a large current loop. With this layout, the third sensor may be more susceptible to radiated noise and have increased emissions. These two sections of ground are the same location on the schematic, so they could potentially be one connected area with a better layout.

Figure 3-6. Improper Current Loop Layout

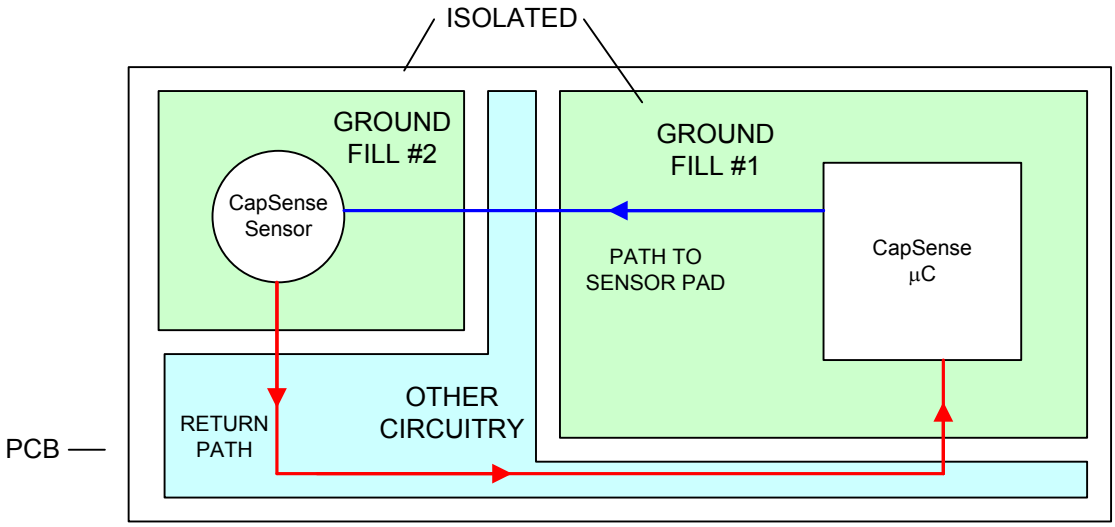
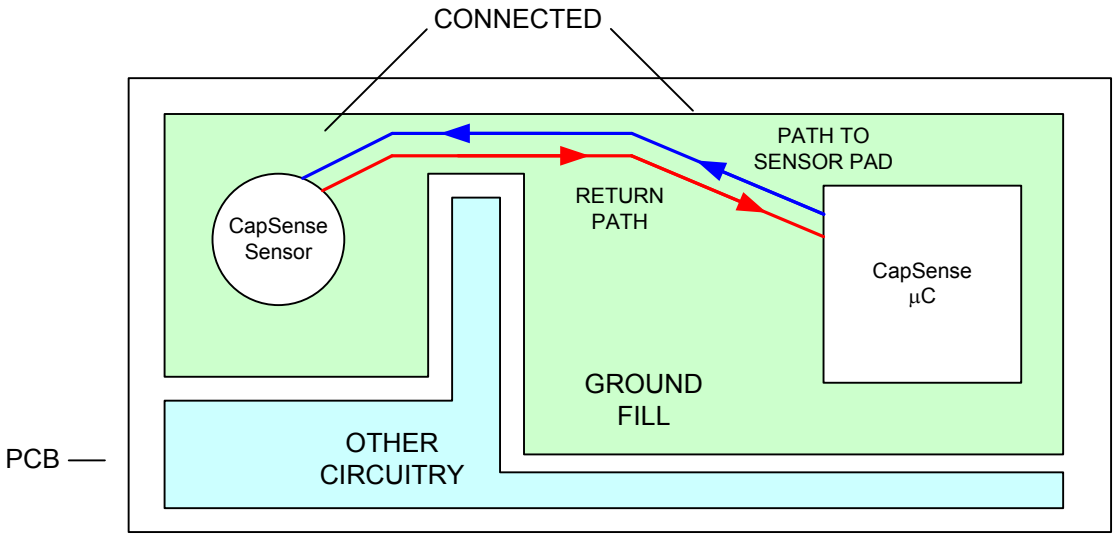


Figure 3-7 illustrates the proper layout for the previous example. The loop area has been reduced by connecting the two grounded areas.

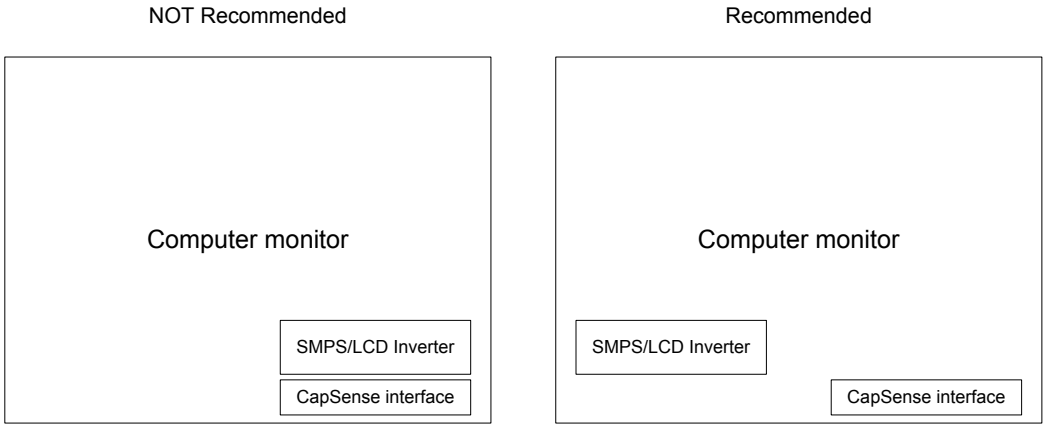
Figure 3-7. Proper Current Loop Layout



3.3.1.5 RF Source Location

When systems like computer monitors or digital photo frames are designed with CapSense devices, care must be taken care to prevent noise from LCD inverters and switched-mode power supplies (SMPS) from upsetting the CapSense system. A simple technique to minimize this kind of interaction is to partition the system with noise sources from CapSense inputs, as demonstrated in Figure 3-8. Due to the practical limitations of product size, the noise source and the CapSense circuitry may only be separated by a few inches. This small separation can provide the extra margin required for good sensor performance compared to the case with close proximity between noise source and CapSense.

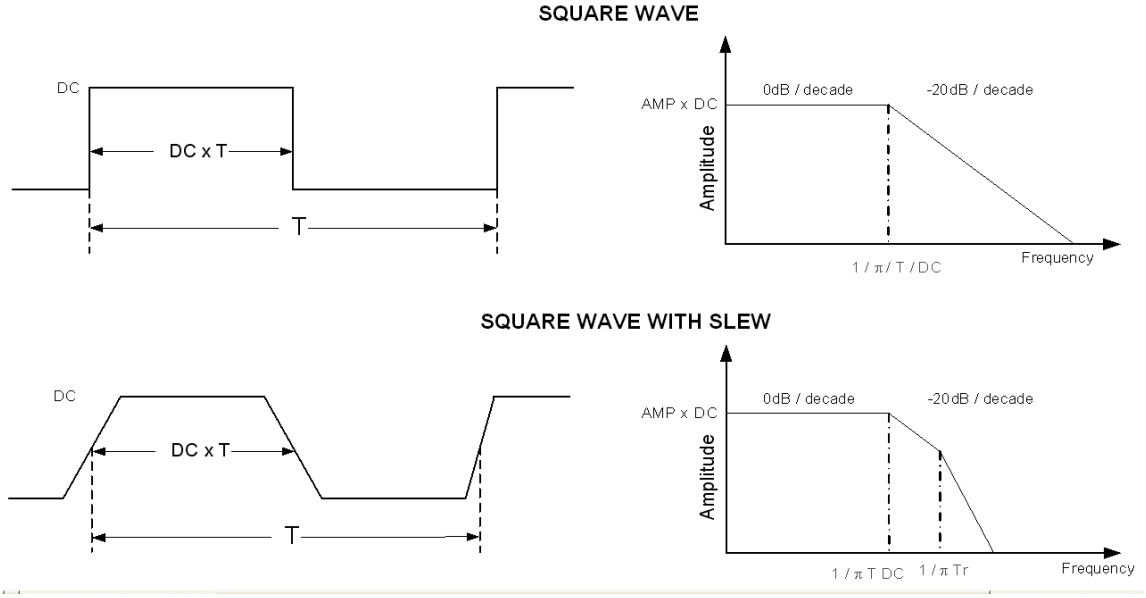
Figure 3-8. Separating Noise Sources



3.3.2 Radiated Emissions

Figure 3-9 shows the impact of rise/fall time of a square wave on the radiated emissions. It is clear that slowing the transitions introduces the cutoff point and damps the radiated energy level. The internal clock signals of the CapSense controller are slew-controlled to reduce the radiated emission.

Figure 3-9. Impact of Slew Rate on Emissions



The CapSense sensing methods use a switched capacitor front end to interact with the sensors. Selecting a low frequency for the switched capacitor clock will help to reduce the radiated noise from the CapSense sensor.

3.3.3 Conducted Immunity and Emissions

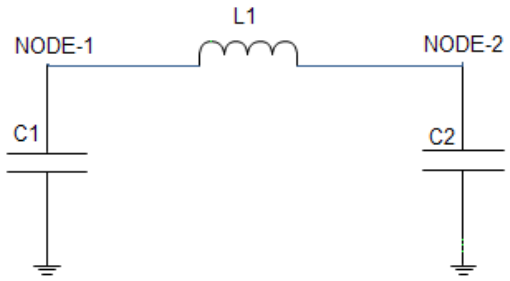
Noise current generated by high frequency switching circuits entering the system through the power and communication lines is called conducted noise.

3.3.3.1 Board Level Solutions

Proper use of decoupling capacitors as recommended by the datasheet can limit the problem with conducted emissions. For further protection, a passive filter can be used. This filter effectively limits not just the conducted noise emitted but also the noise entering the system. Thus it improves the conducted noise immunity of the system.

A pi filter is a simple bidirectional low pass filter. The two main types of pi filters are the series inductor and the series resistor. The series inductor pi filter has two shunt capacitors and one series inductor configured like the Greek letter π, as shown in Figure 3-10.The noise is filtered by all three elements (L1, C1 and C2) in both directions. The bidirectional nature of the filter is very important. Not only does it prevent the supply noise from affecting sensitive parts, it can also prevent the switching noise of the part itself from coupling back onto the power planes.

Figure 3-10. Series Inductor Pi Filter



The values of the components are selected based on the frequency that needs to be attenuated.

3.3.3.2 Power Supply Solutions

The following guidelines will help prevent conducted noise from entering your CapSense design:

- Provide GND and V_{DD} planes that reduce current loops.
- If the CapSense controller PCB is connected to the power supply by a cable, minimize the cable length and consider using a shielded cable.
- Place a ferrite bead around power supply or communication lines to help reduce high frequency noise.

3.4 Software Filtering

Software filters are one of the techniques for dealing with high levels of system noise. Table 3-3 lists the types of filters that have been found useful for CapSense.

Table 3-3. CapSense Filter Types

Type	Description	Application
Average	Finite impulse response filter (no feedback) with equally weighted coefficients	Periodic noise from power supplies
IIR	Infinite impulse response filter (feedback) with a step response similar to an RC filter	High frequency white noise (1/f noise)
Median	Nonlinear filter that computes median input value from a buffer of size N	Noise spikes from motors and switching power supplies
Jitter	Nonlinear filter that limits current input based on previous input	Noise from thick overlay (SNR < 5:1), especially useful for slider centroid data
Event-Based	Nonlinear filter that causes a predefined response to a pattern observed in the sensor data	Commonly used to block generation or posting of non-existent events
Rule-Based	Nonlinear filter that causes a predefined response to a pattern observed in the sensor data	Commonly used during normal operation of the touch surface to respond to special scenarios such as accidental multi-button selection

3.4.1 Average Filter

An average filter is a Finite Impulse Response filter (FIR) with equal-weighted coefficients. Average filters work well with periodic noise. Periodic noise is attenuated by spacing the samples out over one noise cycle. Sample spacing is not critical. For example, power line noise can be anywhere from 50 Hz to 60 Hz. Without adjusting the sampling rate, the average filter works equally well for 50-Hz and 60-Hz noise. Figure 3-11 shows a sample rate that is synchronized with a simple periodic waveform. There is no feedback path in this filter.

Figure 3-11. Synchronized Sample Rate

The general equation for an average filter is:

$$y[i] = \frac{1}{N}(x[i] + x[i-1] + \cdots + x[i-N+1]) \qquad \textbf{Equation 12}$$

Figure 3-12 and Figure 3-13 on page 38 illustrate the results of using an average filter on real CapSense data using the 16-sample filter equation:

$$y[i] = \frac{1}{16}(x[i] + x[i-1] + \cdots + x[i-15]) \qquad \textbf{Equation 13}$$

Figure 3-12. Average Filter Noise (16 Samples)

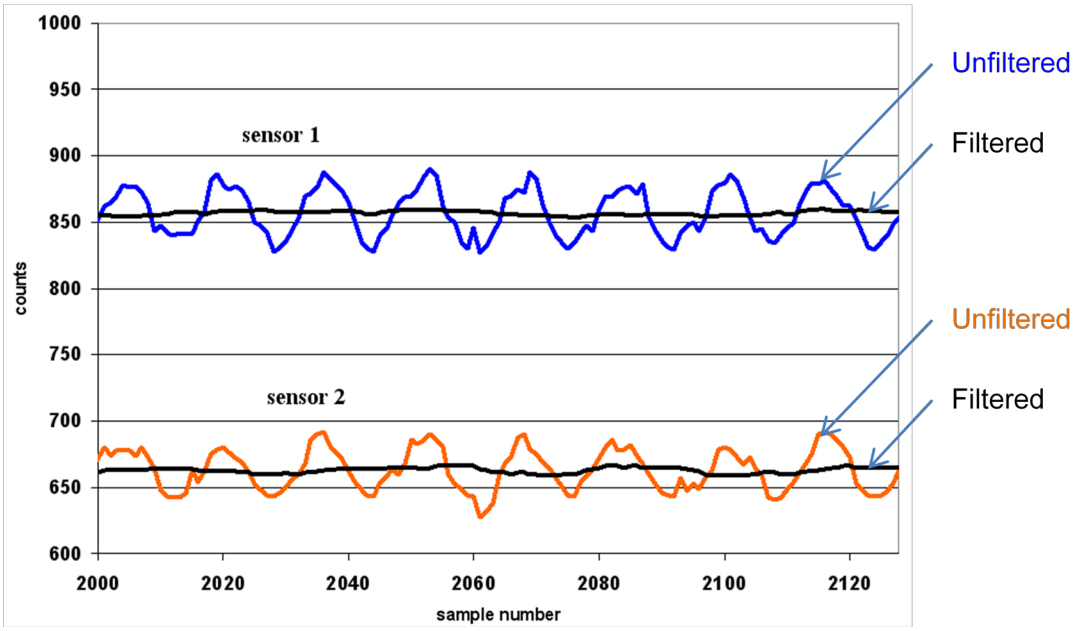
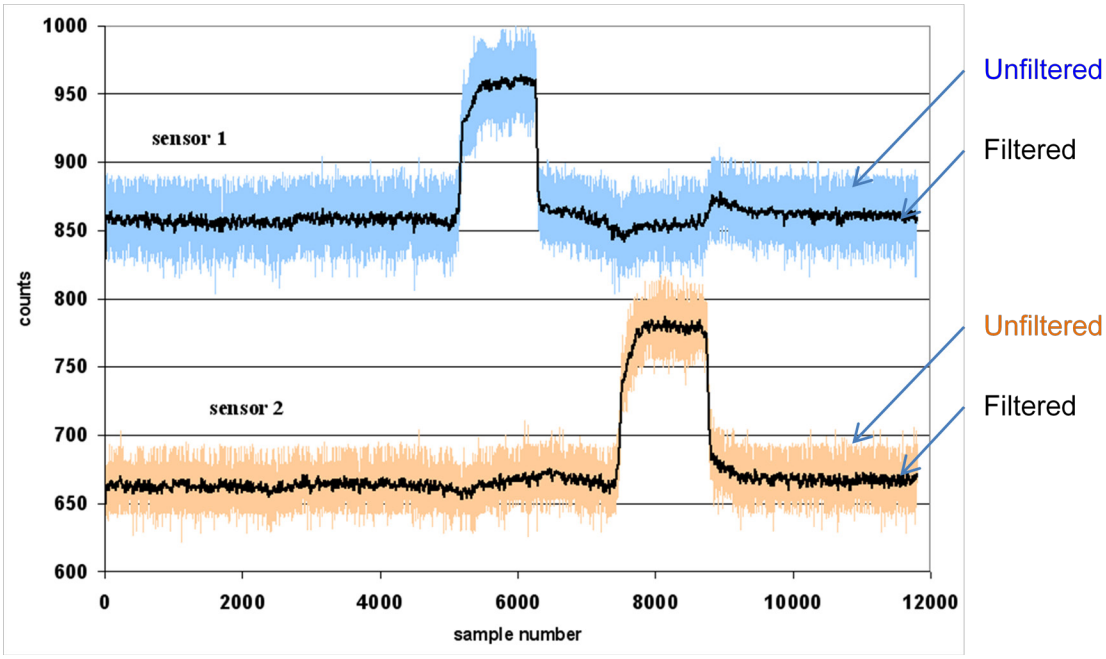


Figure 3-13. Average Filter Finger Touch (16 Samples)



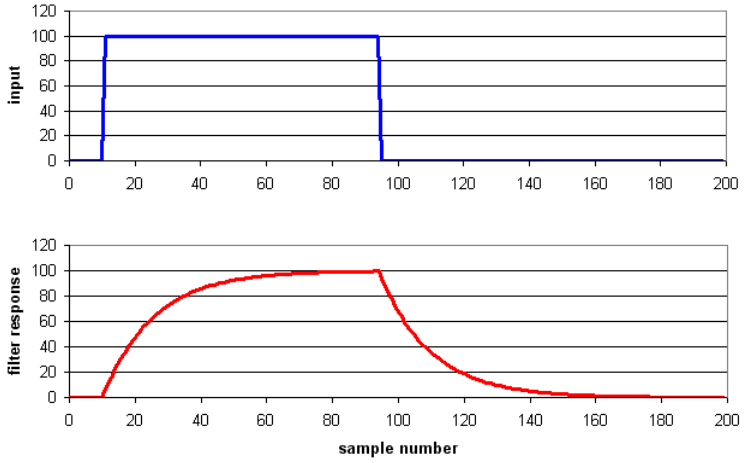
The above examples are representative of power supply noise. The filter works well in this example because the period of the noise is close to the length of the filter (N = 16).

For more information about how to implement an average filter, refer to code example CSA Software Filters with EzI2Cs Slave on CY8C20xx6.

3.4.2 IIR Filter

Infinite Impulse Response filters (IIR) produce a step response similar to RC filters. IIR filters attenuate high frequency noise components and pass lower frequency signals, such as finger touch response waveforms.

Figure 3-14. IIR Filter Step Response



The general equation for a first-order IIR filter is:

$$y[i] = \frac{1}{k}(x[i] + ((k-1) \times y[i-1])) \qquad \textbf{Equation 14}$$

Figure 3-15 and Figure 3-16 on page 40 illustrate the results of using a first-order IIR filter on real CapSense data using the filter equation with k = 16:

$$y[i] = \frac{1}{16}(x[i] + (15 \times y[i-1])) \qquad \textbf{Equation 15}$$

Figure 3-15. IIR Filter Noise

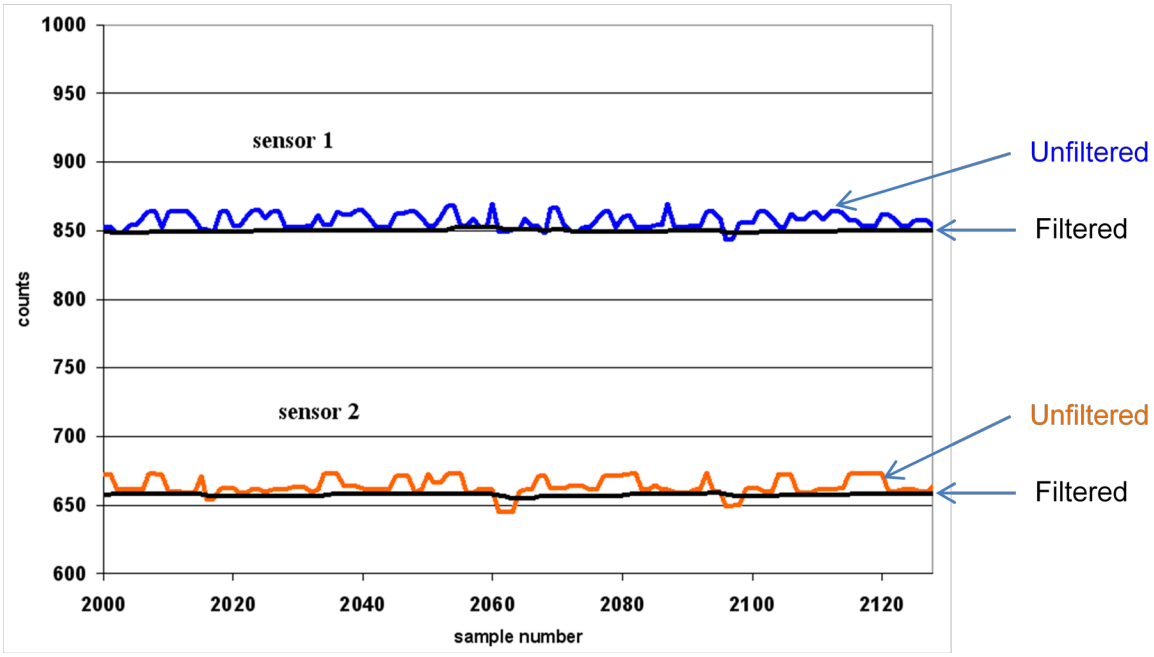
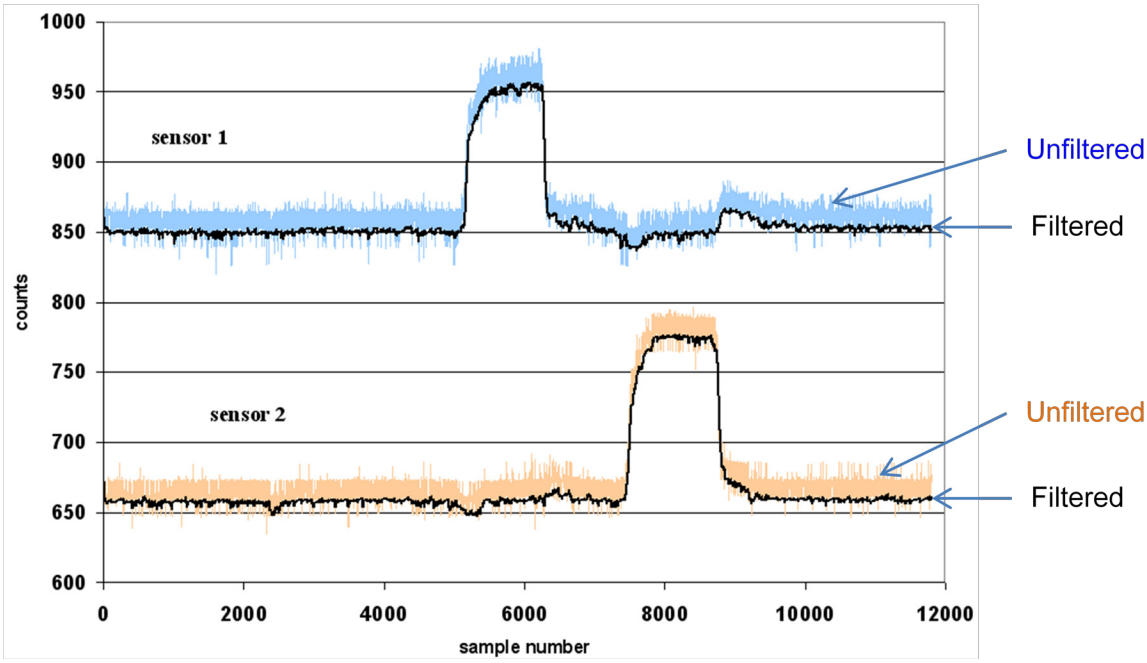


Figure 3-16. IIR Filter Finger Touch



For more information about how to implement an IIR filter, refer to code example CSA Software Filters with EzI2Cs Slave on CY8C20xx6.

3.4.3 Median Filter

Median filters eliminate noise spikes most commonly associated with motors and switching power supplies. In a median filter, a buffer of size N stores the N most recent samples of the input. The median is then computed using a two-step process. First the buffer values are sorted from smallest to largest, then the middle value is selected from the ordered list. The buffer is scanned for the median with each update of the buffer. This is a nonlinear filter. The general equation for a median filter is:

$$y[i] = median(x[i], x[i-1], \ldots, x[i-N+1]) \qquad \textbf{Equation 16}$$

Figure 3-17 and Figure 3-18 on page 41 show the results of using a median filter on real CapSense data using the general filter equation with N = 16.

$$y[i] = median(x[i], x[i-1], \ldots, x[i-15]) \qquad \textbf{Equation 17}$$

Figure 3-17. Median Filter Noise Spike

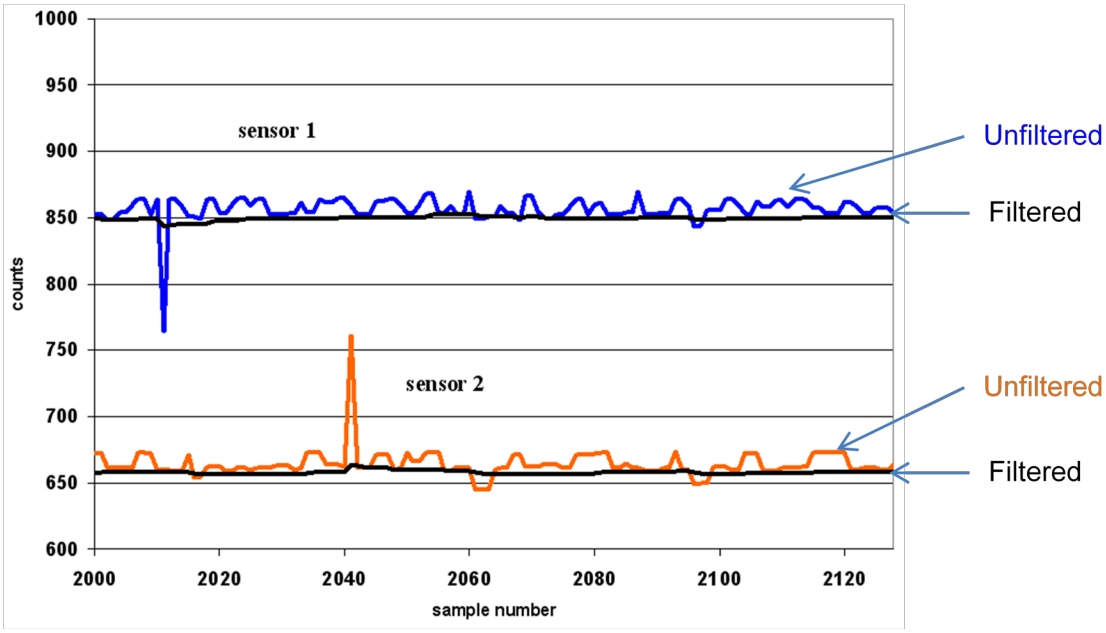
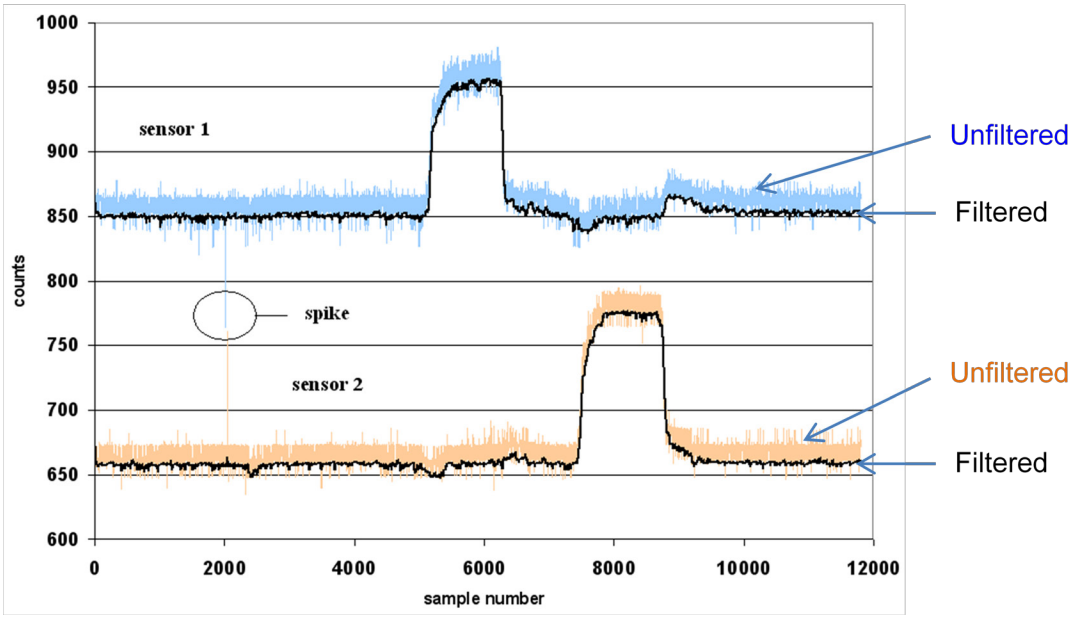


Figure 3-18. Median Filter (16-sample) Finger Touch



For more information about how to implement a median filter, refer to code example CSA Software Filters with EzI2Cs Slave on CY8C20xx6..

3.4.4 Jitter Filter

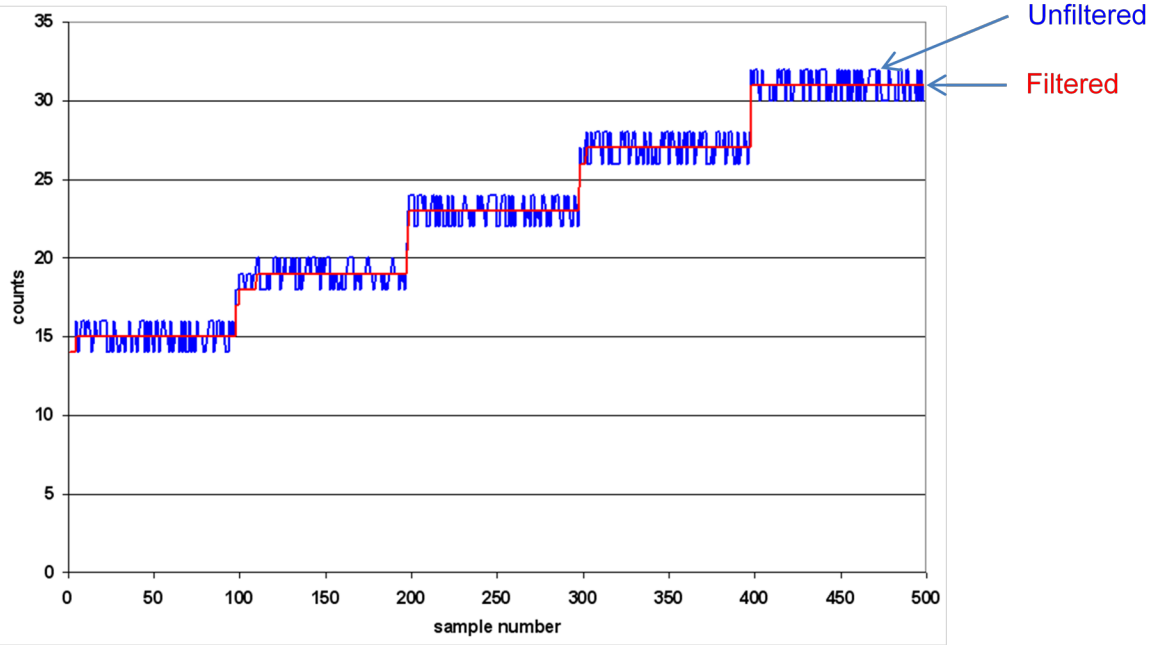
3.4.4.1 Jitter Filter for Noisy Slider Data

The centroid function is used to estimate finger position on a slider. When the signal level is low, usually as a result of thick overlay on the slider, the estimate of finger position will appear to shake and jitter even when the finger is held at a fixed position. This jitter noise can be removed using a jitter filter. To do this, the previous input is stored in a buffer. The current input is compared to the previous output. If the difference is greater than ±1, the output is changed by ±1 (matching sign), as described by Equation 9. This is a nonlinear filter.

$$y[i] = x[i] - 1, \quad if\ x[i] > y[i-1] + 1 \qquad \textbf{Equation 18}$$
$$y[i] = x[i] + 1, \quad if\ x[i] < y[i-1] - 1$$
$$y[i] = y[i-1], \quad otherwise$$

Figure 3-19 shows the results of applying a jitter filter applied to noisy centroid data

Figure 3-19. Jitter Filter Applied to Noisy Centroid Data



3.4.4.2 Jitter Filter for Raw Counts

Although the jitter filter was developed for use with noisy slider data, it has been generalized for use with noisy buttons. If the change in the current input exceeds a set threshold level the output is changed to the previous input plus or minus the threshold amount. The output is not changed if the current input changes by less than the threshold amount. The general equation for a jitter filter applied to buttons is:

$$y[i] = x[i] - threshold, \quad if\ x[i] > y[i-1] + threshold \qquad \textbf{Equation 19}$$
$$y[i] = x[i] + threshold, \quad if\ x[i] < y[i-1] - threshold$$
$$y[i] = y[i-1], \quad otherwise$$

Figure 3-20 and Figure 3-21 on page 43show the result of using a jitter filter on real button data with a large component of periodic noise.

Figure 3-20. Jitter Filter for Button Noise

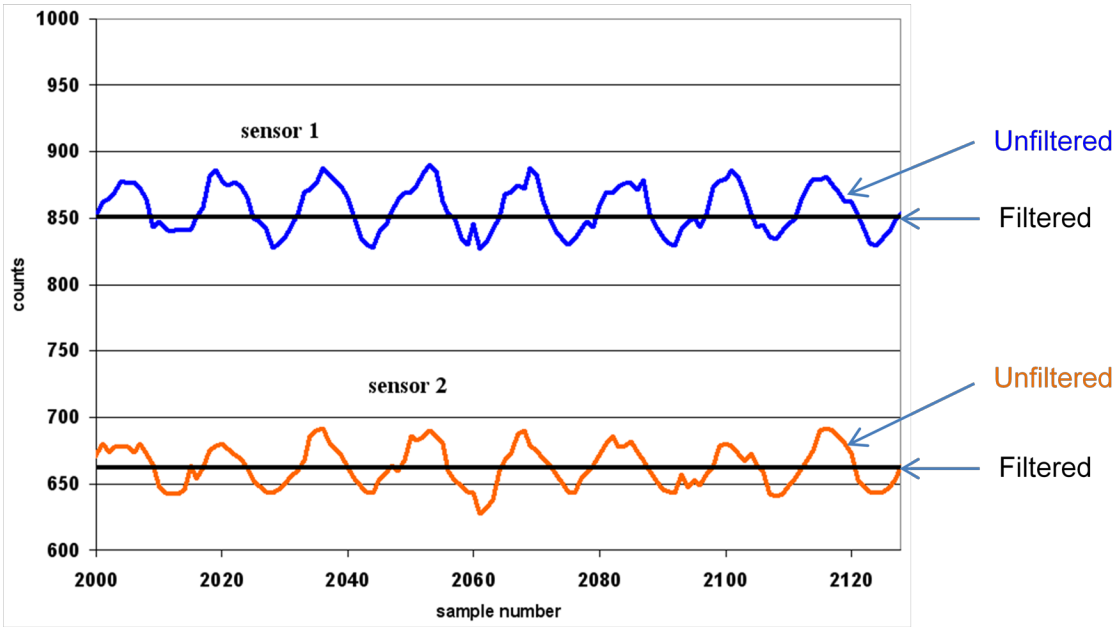
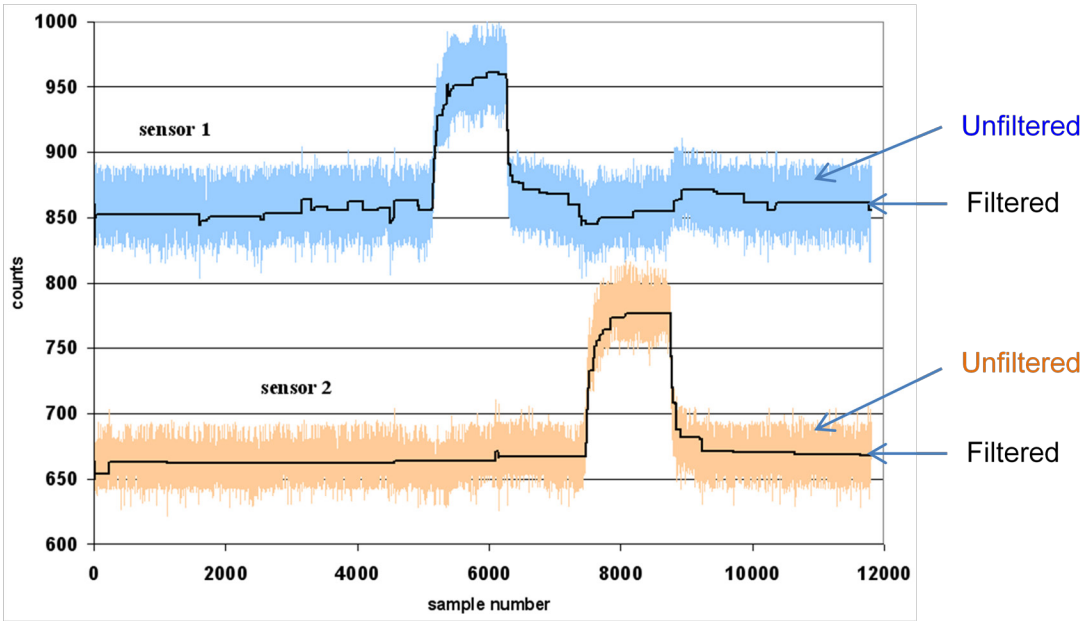


Figure 3-21. Jitter Filter for Button Finger Touch



For more information about how to implement a jitter filter, refer to code example CSA Software Filters with EzI2Cs Slave on CY8C20xx6..

3.4.5 Event Based Filter

Event-based filters involve a special filtering method where a pattern observed in the sensor data causes a predefined response in the CapSense system. The pattern in the data is triggered by an event, such as a handheld product being placed into a pocket, or V_{dd} dropping suddenly in a camera phone when the camera flash circuit is being charged. One common response used with event-based filter is to block CapSense data transmission until the pattern returns to normal. Another common response is to reset the level of the Baseline reference defined in section 2.4.1 Signal-to-Noise Ratio (SNR) .

3.4.6 Rule Based Filter

Rule-based filters are another special filtering method where a pattern observed in the sensor data causes a rule-based response in the CapSense system. Unlike the event-based filter, the rule-based filter acts on patterns in the sensor data that are encountered during normal operation of the touch surface. The rule-based filter takes into account special scenarios on how sensors will be used. For example, with a set of radio channel selection buttons, two buttons can be pressed accidentally, but only one should be selected. The rule-based filter will sort out this kind of situation in a predefined way.

3.5 Power Consumption

Minimizing power consumption is an important design goal. For many CapSense systems extending battery life is critical to the success of the product. In systems that do not utilize batteries, power consumption still plays a role in optimizing power supply designs in order to reduce costs and PCB area.

3.5.1 Active and Sleep Current

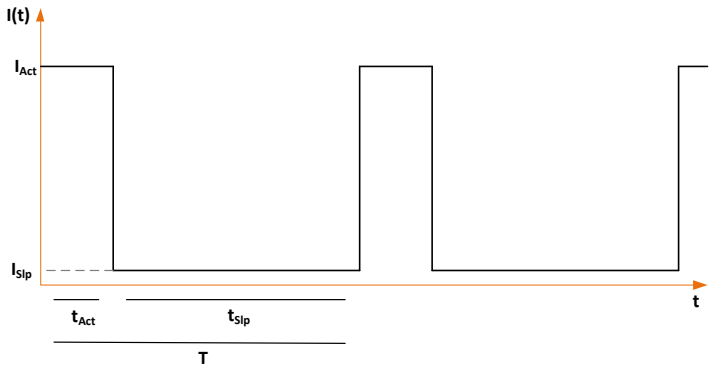
Active current is the current consumed by the device when all selected analog and digital blocks are enabled and the CPU is running. In typical applications, the CapSense controller does not need to be in the active state all the time.

The device can be put into the sleep state to stop the CPU and the major blocks of the device. Current consumed by the device in sleep state is called sleep current. Sleep current is much lower than the active current.

3.5.2 Average Current

In typical applications, sleep state can be invoked periodically to reduce power consumption. This means that during a preset time period, the CapSense controller wakes up from sleep state, performs all necessary operations in the active state (scan all sensors, update all baselines, check if any sensor is in the TOUCH state, etc), and then returns to sleep state. The resulting instantaneous current graph is shown in Figure 3-22.

Figure 3-22. Instantaneous Current



Where:

I(t) = Instantaneous current

I_{Act} = Active current

I_{Slp} = Sleep current

t_{Act} = Active time

t_{Slp} = Sleep time

T = Time period of a cycle

The average current consumed by the device over a long time period can be calculated by using the following equation.

$$I_{AVE} = \frac{(I_{Act} \times t_{Act}) + (I_{Slp} \times t_{Slp})}{T}$$ **Equation 20**

The average power consumed by the device can be calculated as follows:

$$P_{AVE} = V_{DD} \times I_{AVE}$$ **Equation 21**

3.5.3 Response Time vs. Power Consumption

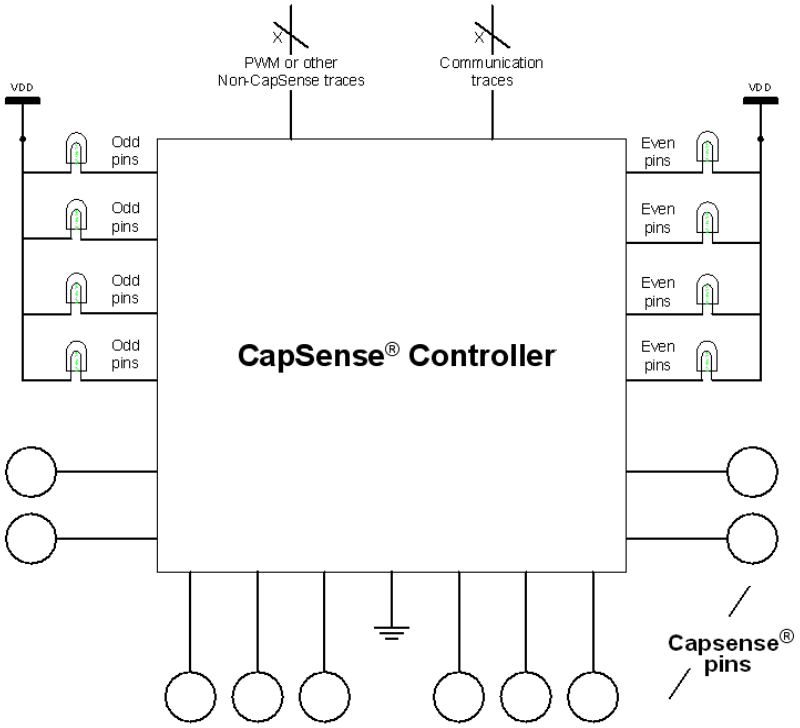
As illustrated in Equation 12, the average power consumption can be reduced by decreasing I_{AVE} or V_{DD}. I_{AVE} may be decreased by increasing sleep time. Increasing sleep time to a very high value will lead to poor response time of the CapSense button. Because of this tradeoff between response time and power consumption, the application developer has to carefully select the sleep time based on system requirements.

In any application, if both power consumption and response time are important parameters to be considered, then, an optimized method can be used which incorporates both continuous-scan and sleep-scan modes. In this method the device spends most of its time in sleep-scan mode where it scans the sensors and goes to sleep periodically as explained in the previous section and thereby consuming less power. When user touches a sensor to operate the system, the device jumps to continuous-scan mode where the sensors are scanned continuously without invoking sleep and thereby giving very good response time. The device remains in continuous-scan mode for a specified time-out period. If the user does not operate any sensor within this time-out period, the device jumps back to the sleep-scan mode.

3.6 Pin Assignments

An effective method to reduce interaction between CapSense sensor traces and communication and non-CapSense traces is to isolate each by port assignment. Figure 3-23 shows a basic version of this isolation for a 32-pin QFN package. Because each function is isolated, the CapSense controller is oriented such that there is no crossing of communication, LED, and sensing traces.

Figure 3-23. Recommended: Port Isolation for Communication, CapSense, and LEDs

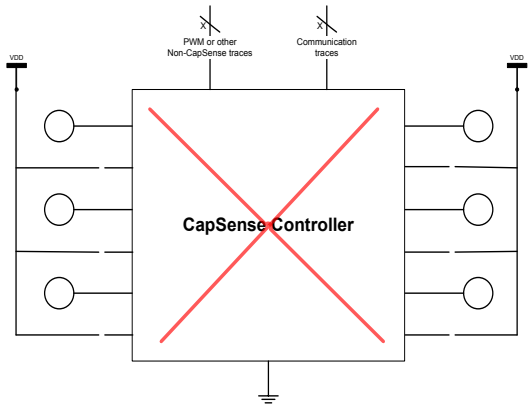


The CapSense controller architecture imposes a restriction on current budget for even and odd port pin numbers. For a CapSense controller, if current budget of odd port pin is 100 mA, total current drawn though all odd port pins should not exceed 100 mA. In addition to the total current budget limitation, there is also maximum current limitation for each port pin. Refer to the datasheet of the CapSense controller used in the application to know the specification of that particular CapSense controller.

All CapSense controllers provide high current sink and source capable port pins. When using high current sink or source from port pins, select the ports that are closest to device ground pin to minimize the noise.

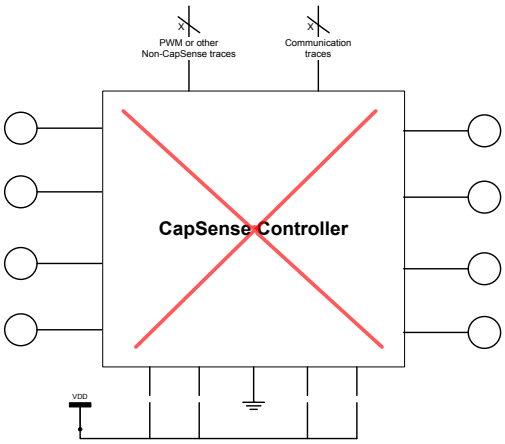
The following two examples demonstrate common pin assignment mistakes. In Figure 3-24 on page 47, CapSense and non-CapSense traces are not isolated, and CapSense pins are far from ground. This is an example of a bad pin assignment.

Figure 3-24. NOT Recommended: Port Isolation for Communication, CapSense, and LEDs



In Figure 3-25, good isolation is achieved, but note that the LEDs are placed next to the ground pin. The CapSense sensors are assigned to edge of the chip that does not include ground. Minimizing the distance between CapSense pins and the ground pin will lead to lower parasitic capacitance for the traces. This is also an example of a bad pin assignment.

Figure 3-25. NOT Recommended: Port Isolation for Communication, CapSense and LEDs



3.7 PCB Layout Guidelines

In the typical CapSense application, the capacitive sensors are formed by the traces of a printed circuit board (PCB) or flex circuit. Following CapSense layout best practices will help your design achieve higher noise immunity, lower C_P, and higher signal to noise ratio (SNR). The CapSense signal drops off at high Cp levels due to drive limits of the internal current sources that are part of the CapSense circuitry. The long time constants associated with high C_P are another reason to avoid high C_P.

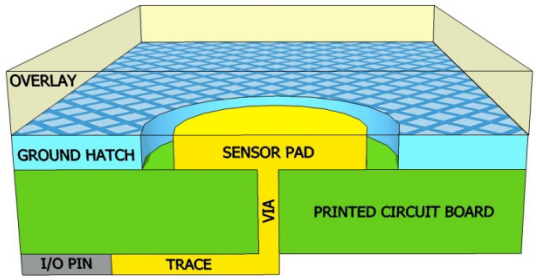
3.7.1 Parasitic Capacitance, C_P

The main components of C_P are trace capacitance and sensor capacitance. C_P is a nonlinear function of sensor diameter, trace length, trace width, and the annular gap. There is no simple relation between C_P and PCB layout features, but here are the general trends. An increase in sensor size, an increase in trace length and width, and a decrease in the annular gap all cause an increase in C_P. One way to reduce C_P is to increase the clearance between the sensor and ground. Unfortunately, widening the gap between sensor and ground will decrease noise immunity.

3.7.2 Board Layers

Most applications use a two-layer board with sensor pads and a hatched ground plane on the top side and all other components on the bottom side. The two-layer stackup is shown in Figure 3-26. In applications where board space is limited or the CapSense circuit is part of a PCB design containing complex circuitry, four-layer PCBs are used.

Figure 3-26. Two-Layer Stackup for CapSense Boards



3.7.3 Board Thickness

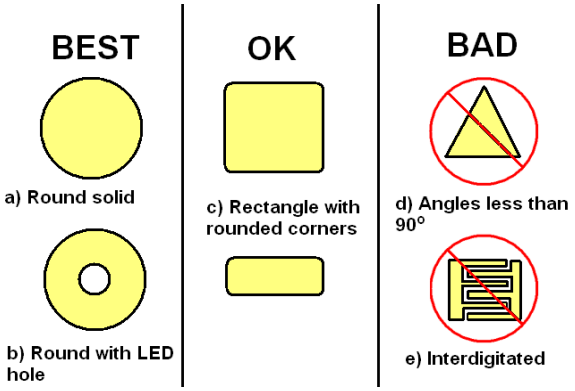
FR4-based PCB designs perform well with board thicknesses ranging from 0.020 inches (0.5 mm) to 0.063 inches (1.6 mm).

Flex circuits work well with CapSense, and are recommended for curved surfaces. All guidelines presented for PCBs also apply to flex. Ideally flex circuits should be no thinner than 0.01 inches (0.25 mm). The high breakdown voltage of the Kapton® material (290 kV/mm) used for flex circuits provides built in ESD protection for the CapSense sensors.

3.7.4 Button Design

The best shape for buttons is round. Rectangular shapes with rounded corners are also acceptable. Sharp points concentrate fields, so avoid sharp corners (less than 90°) when designing your sensor pad.

Figure 3-27. Recommended Button Shapes



Button diameter can range from 5 mm to 15 mm, with 10 mm being suitable for the majority of applications. A larger diameter helps with thicker overlays.

Annular gap size should be equal to the overlay thickness, but no smaller than 0.5 mm, and no larger than 2 mm. For example, a PCB layout for a system with a 1-mm overlay should have a 1-mm annular gap, while a 3-mm overlay design should have a 2-mm annular gap. The spacing between the two adjacent buttons should be large enough that if one button is pressed, a finger should not reach the annular gap of the other button.

3.7.5 Slider Design

A typical slider pattern is shown in Figure 3-28. The recommended dimensions for slider design are given in Table 3-4.

Figure 3-28. Typical Slider Pattern

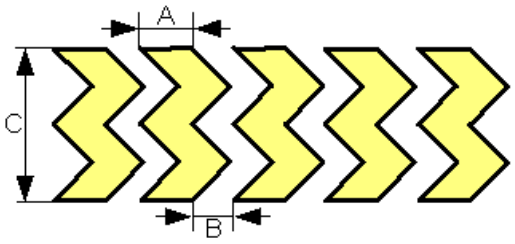


Table 3-4. Slider Dimensions

Parameter	Min	Max	Recommended
Width of the Segment (A)	2 mm	7 mm	Equal to overlay thickness, but within the min/max limits.
Clearance between Segments (B)	0.5 mm	2 mm	Equal to sensor to ground clearance
Height of the segment (C)	7 mm	15 mm	12 mm

3.7.6 Sensor and Device Placement

Minimize trace length from CapSense controller pins to the sensor pad in order to optimize signal strength.

Series resistors should be mounted within 10 mm of the controller pins to reduce RF interference and provide ESD protection.

Mount the controller and all other components on the bottom layer of the PCB.

Isolate switching signals such as PWM, I^2C communication lines, and LEDs from the sensor and the sensor PCB traces. Do this by placing them at least 4 mm apart and fill a hatched ground between CapSense traces and non-CapSense traces to avoid crosstalk.

Connectors between the sensor and the controller pins are not recommended since connectors increase C_P and decrease noise immunity.

3.7.7 Trace Length and Width

The parasitic capacitance of the traces and sensor pad should be minimized. Trace capacitance is minimized when they are short and narrow.

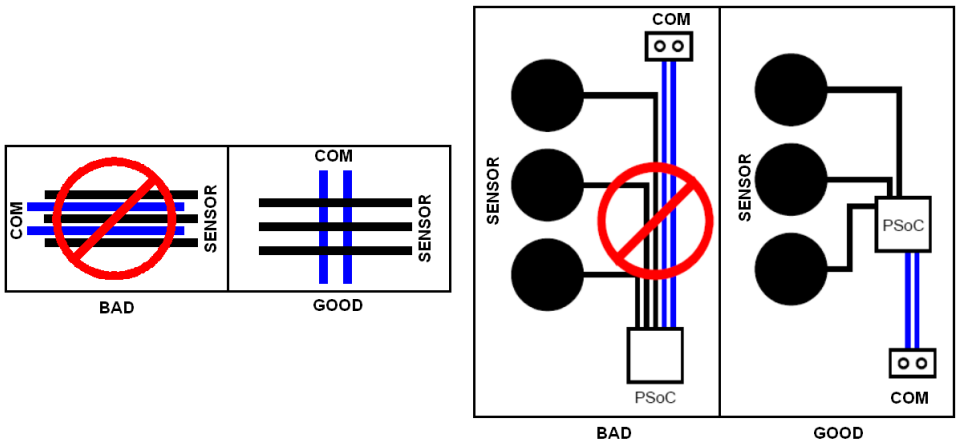
- **Trace length** must be less than 12 inches (300 mm) for a standard PCB and less than 2 inches (50 mm) on flex circuits.
- **Trace width** should be no greater than 7 mil (0.18 mm). CapSense traces should be surrounded by hatched ground with trace-to-ground clearance of 10 mil to 20 mil (0.25 mm to 0.51 mm).

3.7.8 Trace Routing

Route sensor traces on the bottom layer of the PCB. This way the only user interaction with the CapSense sensors is with the active sensing area. Do not route traces directly under any sensor pad unless the trace is connected to that sensor.

Do not run capacitive sensing traces in close proximity to communication lines, such as I^2C or SPI masters. If it is necessary to cross communication lines with sensor pins, make sure the intersection is at right angles, as illustrated in Figure 3-29.

Figure 3-29. Routing of Sensing and Communication Lines



3.7.9 Crosstalk Solutions

A common backlighting technique for panels is to mount an LED under the sensor pad so that it shines through a hole in the middle of the sensor. When the LED is switched on or off, the voltage transitions on the trace that drives the LED can couple into the capacitive sensor input, creating noisy sensor data. This coupling is referred to as crosstalk. To prevent crosstalk CapSense and non-CapSense traces should be isolated from one another. A minimum separation of 4 mm is recommended. A hatched ground plane also can be placed between those traces to isolate them. LED drive traces and CapSense traces should not be routed together.

Figure 3-30. NOT Recommended - LED and CapSense in Close Proximity

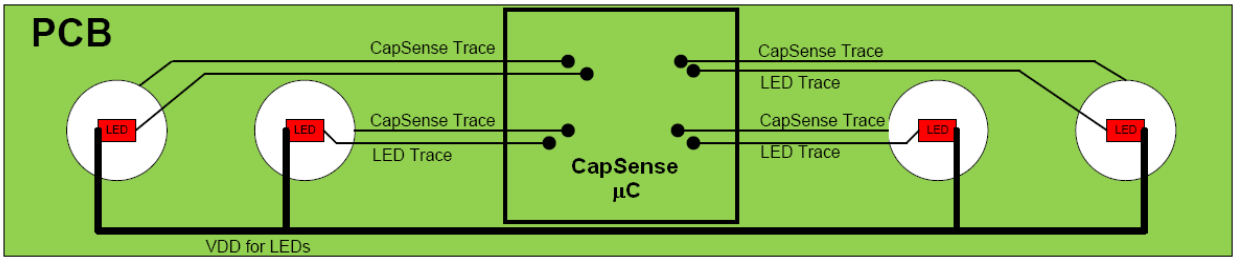
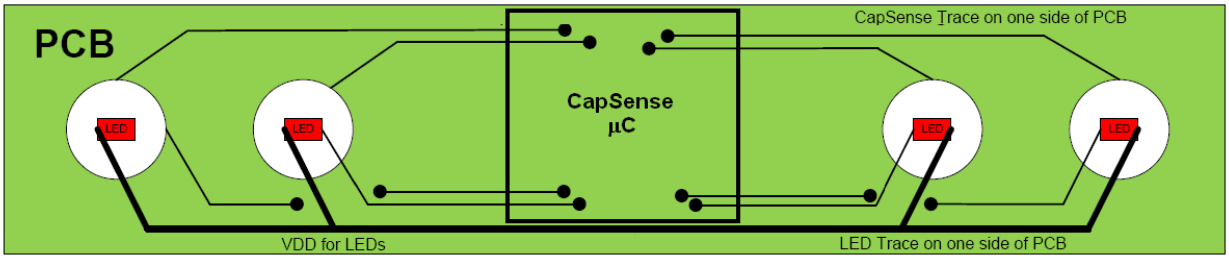
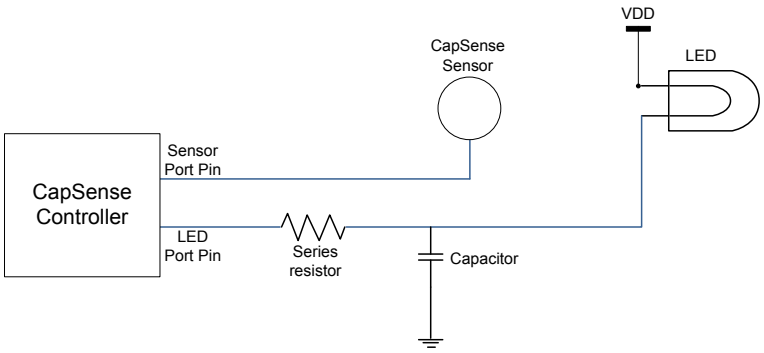


Figure 3-31. Recommended - LED and CapSense with Wide Separation



Another approach to reducing crosstalk is to slow down the rising and falling edges of the LED drive voltage using a filter capacitor. Figure 3-32 shows an example circuit of this solution. The value of the added capacitor depends on the drive current requirements of the LED; however, a value of 0.1 µF is typical.

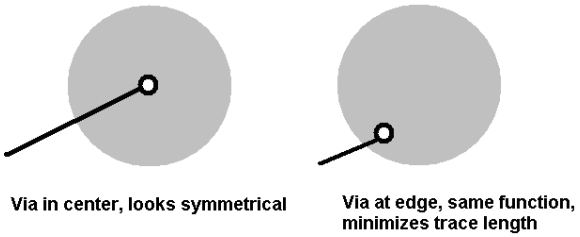
Figure 3-32 Filter Capacitor Solution for Crosstalk



3.7.10 Vias

Use the minimum number of vias to route CapSense inputs to minimize parasitic capacitance. The via should be placed to minimize the trace length, which is usually on the edge of the sensor pad, as shown in Figure 3-33.

Figure 3-33. Via Placement on Sensor Pad



3.7.11 Ground Plane

Ground fill is added to both the top and bottom of the sensing board. When ground fill is added near a CapSense sensor pad, there is a tradeoff between maintaining a high level of CapSense signal and increasing the noise immunity of the system. Typical hatching for the ground fill is 15 percent on the top layer (7 mil line, 45 mil spacing) and 10 percent on the bottom layer (7 mil line, 70 mil spacing).

Figure 3-34. Recommended Button and Slider Layout Top Layer

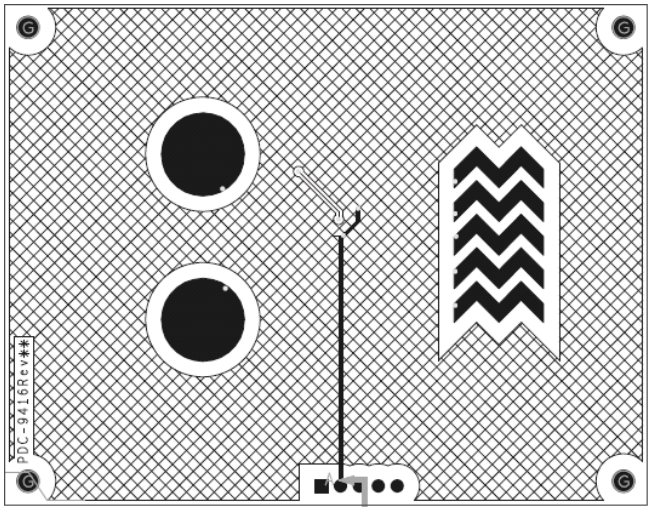
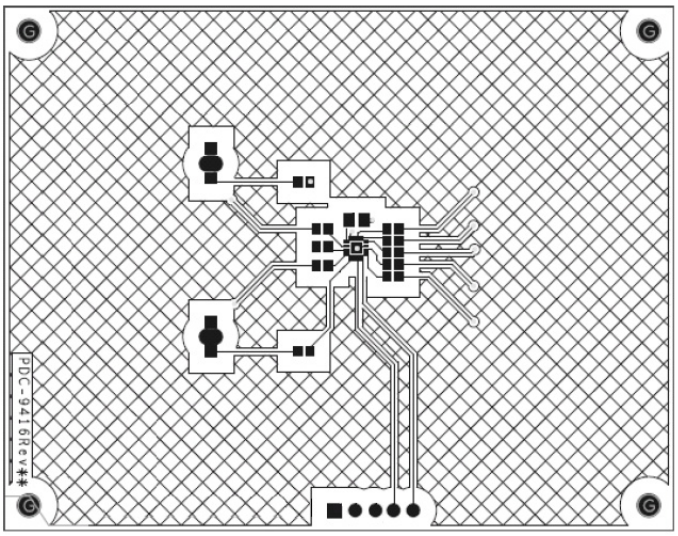


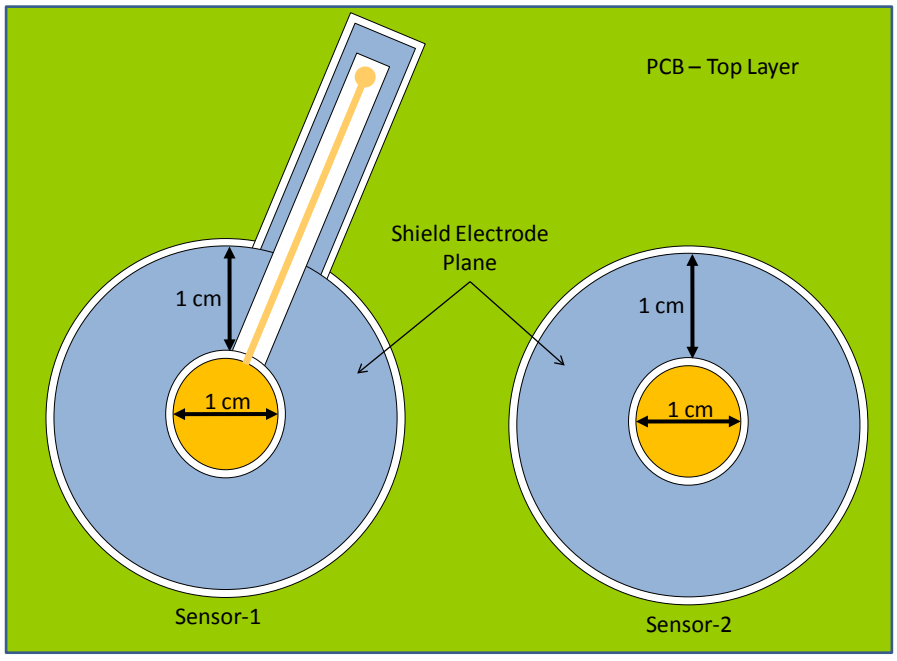
Figure 3-35. Recommended Button and Slider Layout Bottom Layer



3.7.12 Shield Electrode and Water Tolerance

Fingers and water interact in a similar, but not identical, way with electric fields. There is enough difference between the two to make possible techniques for discriminating between a touch and a spill. On printed circuit boards and flex circuits, a practical level of water tolerance is achieved with the use of a shield electrode. These special electrodes add no material cost to the system because they are incorporated into the same circuit board layout as the touch sensor. The purpose of the shield electrode is to set up an electric field pattern around the touch sensors that helps attenuate the effects of water. The shield electrode works by mirroring the voltage of the touch sensor on the shield. To learn more about how water tolerance is achieved with a shield electrode, refer to Cypress Application Note AN2398, *Capacitance Sensing - Waterproof Capacitance Sensing*.

Figure 3-36. Shield Electrode Plane



Providing a large shield plane on the PCB sometimes invites radiated emission issues. Ways to reduce emissions include:

- **Reduce the size of the shield patterns**: The shield electrode pattern should surround the sensor pad and exposed traces, and spread no further than 1 cm from these features. Spreading the shield electrode beyond 1 cm has negligible effect on system performance. If board space is limited, the shield can spread less than 1cm. In Figure 3-36 on page 53, Sensor-1 shows an example of a shield pattern surrounding a sensor pad and trace routed on the top layer. Sensor-2 shows an example of a shield pattern with a sensor pad without a trace on the top layer.
- **Drive the shield only when required**: In CapSense controllers, when the shield is enabled, it is driven all the time with a waveform that mirrors the waveform on the sensor pad. Driving the shield only during a scan will minimize emissions. To drive the shield only during a scan, you need to insert additional code into the firmware.
- **Limit placement of the shield to select board features**: If the shield electrode is being used to reduce parasitic capacitance, then place the shield only on those sensors that can benefit from reduced C_P. Placing the shield everywhere will increase emissions without any gain in performance. When scanning a sensor that does not need the shield electrode, the shield electrode can be disabled in the firmware.
- **Slow the edges of the shield waveform**: The slew rate of shield electrode can be reduced by adding a filter capacitor between the shield electrode port pin and ground.

4. CapSense Product Portfolio

Cypress's CapSense Controller solutions are based on our Programmable System on Chip (PSoC) platform and offer a wide range of features.

4.1 Cypress's CapSense Controller Solutions

Cypress is the world leader in Capacitive Sensing technologies. Cypress's broad range of solutions provides robust noise immunity, enable quick time to market and system scalability. With CapSense controllers you can:

- Replace mechanical components with simple CapSense buttons and sliders.
- Reduce total BOM cost and form factor by integrating CapSense with other system components.
- Optimize board space with our small form factor packaging (WLCSP, SOIC, and QFN).
- Use our advanced sensing techniques for easy finger detection through 15 mm of glass or 5 mm of plastic.
- Get to market more quickly using SmartSense Auto-Tuning.
- Implement additional user interface functionality such as LED effects, proximity and water rejection.

Cypress offers a wide range of configurable and programmable CapSense controllers. Configurable CapSense controllers are hardware or I^2C configurable. Programmable devices provide complete flexibility to meet your exact design requirements, including reducing BOM cost by integrating further system functionality. The different CapSense device families are listed below.

4.1.1 CapSense Express Controllers (Configurable Solutions)

4.1.1.1 CY8CMBR2044

The CY8CMBR2044 device features a wide operating voltage range, 1.71-V to 5.5-V operating voltage and CSD capacitive sensing with SmartSense Auto-Tuning. These devices are hardware configurable, no I^2C required.

4.1.1.2 CY8C201xx

CY8C201xx devices feature configurable I/Os that can be used as capacitive sensing inputs or as GPIOs for driving LEDs, interrupt outputs, wake-up on interrupt inputs and other digital I/O functionalities. These devices support register-based configuration through an I^2C interface.

4.1.2 CapSense Controllers (Programmable Solutions)

4.1.2.1 CY8C20x34, CapSense

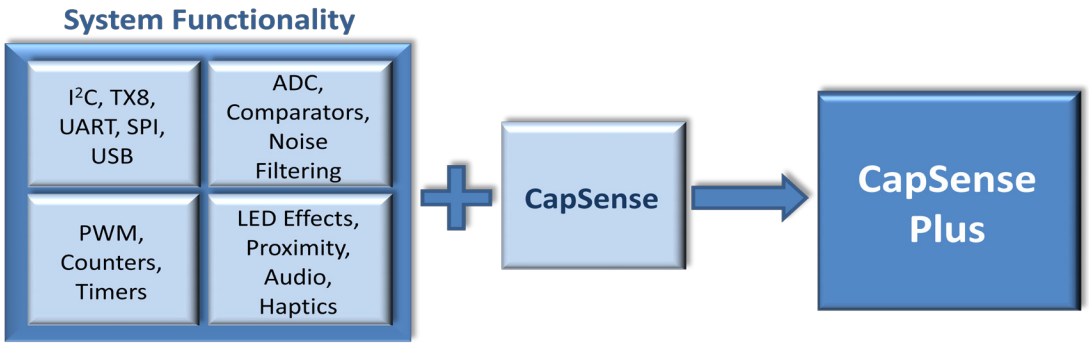
CY8C20x34 devices feature CSA_EMC capacitive sensing and can implement up to 25 CapSense buttons.

4.1.2.2 CY8C20x36A, CapSense

CY8C20xx36A devices can operate at voltages as low as 1.71 V to 5 V, offer both CSA_EMC and CSD capacitive sensing, SmartSense, and support up to 33 CapSense buttons.

4.1.3 CapSense Plus (Programmable Solutions)

Figure 4-1 CapSense Plus



CapSense Plus devices feature capacitive touch sensing and additional system functionality. Using CapSense Plus devices can result in significant cost savings. Additional features include:

- Feedback - LED, Audio, Haptics
- Communication - I^2C, TX8, UART, SPI, USB
- Digital functions - PWM, Counters, Timers
- Analog functions - ADC, Comparator
- Bootloaders

4.1.3.1 CY8C20xx6A, CapSense Plus

CY8C20xx6A devices can operate at voltages as low as 1.71 V to 5 V, offer both CSA_EMC and CSD capacitive sensing and SmartSense, and support up to 33 CapSense buttons, USB, I^2C, SPI., and up to 32-KB Flash memory.

4.1.3.2 CY8C21x34/B, CapSense Plus

CY8C21x34 devices feature CSD capacitive sensing and SmartSense sensing (CY8C21x34B) with advanced digital and analog peripherals, are water tolerant, and can support up to 24 CapSense buttons.

4.1.3.3 CY8C24x94, CapSense Plus

CY8C24x94 devices feature CSD capacitive sensing, proximity sensing, are water tolerant, support a wide range of interfaces (SPI, I^2C USB 2.0 and UART), and can support up to 44 CapSense buttons.

4.1.3.4 Dynamic Reconfiguration

Dynamic reconfiguration is a clever way to optimize total system cost. There are situations in which the number of digital and analog blocks required by a particular application exceeds the resources of the chip. In these situations, it may be possible to time-share the analog and digital blocks. The process of reusing analog and digital resources at different points in time is called dynamic reconfiguration. If the application requires CapSense, an ADC, and a counter, but not all at the same time, reconfiguring the hardware blocks dynamically will enable all features to be implemented. For more information about dynamic reconfiguration, see the Cypress application note *CapSense PLUS Dynamically Configuring CapSense*.

5. CapSense Selector Guide

5.1 Selecting the Right CapSense Device

Several key system requirements must be considered when selecting the best CapSense device for your application.

- Flash and RAM requirements
- Operating voltage range
- Configurable/Programmable
- Number and type of capacitive sensors
- Tuning method
- Water tolerance
- Feedback
- Package size and pin count
- Additional features, such as ADC, communication protocol, and timers

Figure 5-1 on page 58 provides a high level guide to the CapSense devices based on design requirements. Table 5-1 on page 59 identifies the key features for each CapSense product family. After completing the selection process, the next step in your development cycle is to consult the more detailed design guide for the selected device. Please refer to Device Specific Design Guides found in the Resources section.

Figure 5-1 Device Selection Tree

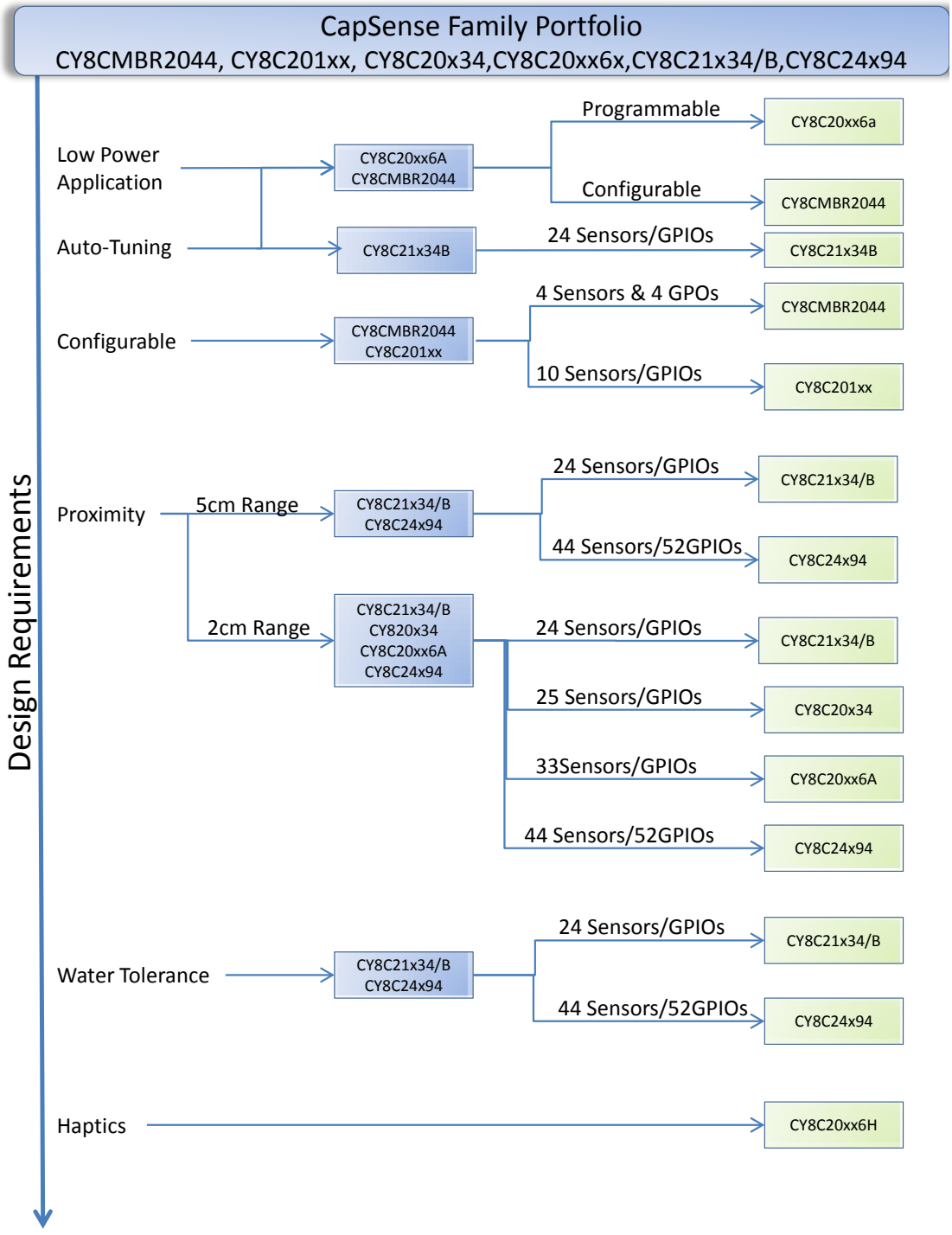


Table 5-1. CapSense Key Features by Product Family

		Product Family					
		CY8CMBR2044	CY8C201xx	CY8C21x34/B	CY8C20x34	CY8C20xx6A/H	CY8C24x94
Feature	RAM (Bytes)			512	512	1 K/2 K	1 K
	Flash (Bytes)			8 K	8 K	8 K/16 K/32 K	16 K
	Operating Voltage	1.71 V–5.5 V	2.4 V–5.25 V	2.7 V–5.25 V	2.4 V–5.25 V	1.71 V–5.5 V	3.0 V–5.25 V
	Configurable	Yes	Yes				
	Programmable			Yes	Yes	Yes	Yes
	Maximum Number of Sensors	4	10	24	25	33	44
	Buttons	Yes	Yes	Yes	Yes	Yes	Yes
	Sliders		Yes	Yes	Yes	Yes	Yes
	Proximity			Yes	Yes	Yes	Yes
	CSD	Yes		Yes		Yes	Yes
	CSA_EMC		Yes		Yes	Yes	
	CSDADC			Yes			Yes
	SmartSense	Yes		Yes (B)		Yes	
	I2C		HW Slave	Master and Slave Interface	Master and Slave Interface	Master and Slave Interface	Master and Slave Interface
	SPI			Master and Slave Interface	Master and Slave Interface	Master and Slave Interface	Master and Slave Interface
	UART			UART	Softw are	Softw are	UART
	USB					Full speed USB	Full speed USB
	Timer			8- to 32-bit timer/counter	13-bit timer	16-bit timer	8- to 32-bit timer/counter
	PWM			8- to 32-bit deadband option			8- to 32-bit
	LED			7-segment support	7-segment support		7-segment support
	LCD			20x2 controller interface	20x2 controller interface	20x2 controller interface	20x2 controller interface
	EEPROM			Emulation	Emulation	Emulation	Emulation
	Water			Tolerant			
	Bootloader			I2C	I2C	I2C Full speed USB	I2C Full speed USB
	Feedback					Haptics	
	Comparators			Yes	Yes	Yes	
	ADC			8- and 10-bit		8- and 10-bit	7- to 13-bit
	DAC						6,8 and 9-bit
	Random Sequencer						8- to 32-bit pseudo
	Amplifiers						Yes
	Filter						2-pole band and low pass

6. CapSense Migration Paths

As a system evolves, it may require a CapSense controller with more advanced features. The following sections describe possible migrations among CapSense controllers.

6.1 CY8C20x34 to CY8C20xx6A/H

CY8C20xx6A/H devices implement CSA_EMC using dedicated hardware similar to that in CY8C20x34. Therefore, upgrading your design from CY8C20x34 to CY8C20xx6A does not require any external hardware or firmware changes, simply clone your PSoC Designer project to CY8C20xx6A.

Advantages of CY8C20xx6A/H over CY8C20x34:

- More I/O pins
- Wider operating voltage range
- Lower power consumption
- Immersion TS2000 Haptics Technology for ERM control

6.2 CY8C21x34/B / CY8C24x94 to CY8C20xx6A/H

All three devices feature CSD capacitive sensing. CY8C20xx6A/H devices implement CSD using dedicated hardware as opposed to programmable digital and analog blocks as in CY8C21x34/B and CY8C24x94 devices. Furthermore, CY8C21x34/B and CY8C24x94 devices use an external bleed resistor in the current measuring circuit, whereas CY8C20xx6A/H devices use an on-chip iDAC. These architectural differences necessitate different external circuitry, user module parameters, and settings for similarly named parameters and APIs between the devices.

Advantages of CY8C20xx6A/H over CY8C21x34/B and CY8C24x94:

- Eliminates an external hardware component
- Wider operating voltage range
- Lower power consumption
- Immersion TS2000 Haptics Technology for ERM control

6.3 CY8C20xx6A/H to CY8C21x34/B / CY8C24x94

All three devices feature CSD capacitive sensing. CY8C20xx6A/H devices implement CSD using dedicated hardware as opposed to programmable digital and analog blocks as in CY8C21x34/B and CY8C24x94 devices. Furthermore, CY8C21x34/B and CY8C24x94 devices use an external bleed resistor in the current measuring circuit, whereas CY8C20xx6A/H devices use an on-chip iDAC. These architectural differences necessitate different external circuitry, user module parameters, and settings for similarly named parameters and APIs between the two devices. If the USB module is used in CY8C20xx6A, then migration is not possible to CY8C21x34/B.

Advantages of CY8C21x34/B and CY8C24x94 over CY8C20xx6A/H:

- Proximity up to 5 cm
- Water tolerance

6.4 Pin-to-Pin Compatibility

When migrating from one device to another, no PCB change is required if you assign the same pin functionality to the new device. If this is the case, then the two devices are pin-to-pin compatible. Table 6-1 gives information about available device packages and pin-to-pin compatibility between the same packages of CY8C20x34, CY8C21x34/B, CY8C20xx6A and CY8C24x94 devices.

Table 6-1. Pin-to-Pin Compatibility

Package	Device			
	CY8C20x34	CY8C21x34/B	CY8C20xx6A/H	CY8C24x94
16 QFN	N[a]	-	N[a]	-
16 SOIC	N	N	-	-
24 QFN without USB	Y	-	Y	-
28 SSOP	Y	Y	-	-
30 WLCSP	N	-	N	-
32 QFN without SMP	Y	Y	Y[b]	-

a. Pin 2 is different; CY8C20x34 → P2[1], CY8C21x34/B → P2[3]. If Pin 2 is used, firmware has to be modified for migration.
b. Without USB

Symbols:

Y pin-to-pin compatible (same package dimensions)

N packages not pin-to-pin compatible

- package not available

For more details, see the "Pin Information" section of the respective datasheets.

7. Resources

7.1 Website

At the Cypress CapSense Controllers website you can access all of the reference material discussed in this section as well as device specific Datasheets and Design Guides.

7.2 Device Specific Design Guides

Design guides are available for each CapSense family of devices. These documents are intended for design engineers who are familiar with capacitive sensing technology and have selected a family of devices.

- CY8C20x34 CapSense® Design Guide
- CY8C20xx6A/H CapSense® Design Guide
- CY8C21x34/B CapSense® Design Guide
- CY8CMBR2044 CapSense® Design Guide

7.3 Technical Reference Manuals

Cypress has created the following technical reference manuals to provide quick and easy access to information on CapSense controller functionality including top-level architectural diagrams, register summaries, and timing diagrams.

- CY8C201xx : Register Reference Guide
- PSoC® CY8C20x66, CY8C20x66A, CY8C20x46/96, CY8C20x46A/96A, CY8C20x36, CY8C20x36A Technical Reference Manual (TRM)
- CY8CPLC20, CY8CLED16P01, CY8C29x66, CY8C27x43, CY8C24x94, CY8C24x23, CY8C24x23A, CY8C22x13, CY8C21x34, CY8C21x23, CY7C64215, CY7C603xx, CY8CNP1xx, and CYWUSB6953 PSoC® Programmable System-on-Chip TRM
- PSoC® CY8C20x24, CY8C20x34 Technical Reference Manual (TRM)

7.4 Development Kits

7.4.1 Universal CapSense Controller Kits

Universal CapSense Controller Kits feature pre defined control circuitry and plug-in hardware to make prototyping and debugging easy. Programming and I^2C-to-USB Bridge hardware are included for tuning and data acquisition.

- CY3280-20x34 Universal CapSense Controller
- CY3280-21x34 Universal CapSense Controller
- CY3280-20xx6A Universal CapSense Controller
- CY3280-24x94 Universal CapSense Controller

7.4.2 Universal CapSense Module Boards

7.4.2.1 Simple Button Module Board

The CY3280-BSM Simple Button Module consists of ten CapSense buttons and ten LEDs. This module connects to any CY3280 Universal CapSense Controller Board.

7.4.2.2 Matrix Button Module Board

The CY3280-BMM Matrix Button Module consists of eight LEDs as well as eight CapSense sensors organized in a 4x4 matrix format to form 16 physical buttons. This module connects to any CY3280 Universal CapSense Controller Board.

7.4.2.3 Linear Slider Module Board

The CY3280-SLM Linear Slider Module consists of five CapSense buttons, one linear slider (with ten sensors), and five LEDs. This module connects to any CY3280 Universal CapSense Controller Board.

7.4.2.4 Radial Slider Module Board

The CY3280-SRM Radial Slider Module consists of four CapSense buttons, one radial slider (with ten sensors), and four LEDs. This module connects to any CY3280 Universal CapSense Controller Board.

7.4.2.5 Universal CapSense Prototyping Module

The CY3280-BBM Universal CapSense Prototyping Module provides access to every signal routed to the 44-pin connector on the attached controller board(s). The Prototyping Module board is used in conjunction with a Universal CapSense Controller board to implement additional functionality that is not part of the other single-purpose Universal CapSense Module boards.

7.4.3 CapSense Express Evaluation Kits for CY8C201xx

CY8C3218-CAPEXP series of CapSense Express evaluation kits available for CY8C201xx family of devices enables designers to replace mechanical buttons/ sliders by implementing touch sensing designs with the CapSense Touch Sensing Family, CapSense Express. With Cypress's PSoC Express™ visual embedded system design tool and CapSense Express configuration tool, designers configure, monitor, and tune buttons or sliders, LEDs, and other general purpose I/Os over I^2C in a real time using a graphical user interface. The following are the lists of CapSense Express evaluation kits available for CY8C201xx family of devices.

- CY3218-CAPEXP1 CapSense Express Kit (Up to 10 I/O for Buttons) with CY8C20110 device
- CY3218-CAPEXP2 CapSense Express Kit (Up to 10 I/O for Sliders) with CY8C201A0 device
- CY3218-CAPEXP3 CapSense Express Kit (Up to 4 I/O for Buttons) with CY8C20142 device

7.4.4 CapSense Express Evaluation Kits for CY8CMBR2044

CY3280-MBR CapSense Express kit for CY8CMBR2044 device enables designers to replace mechanical buttons with CapSense buttons. Designers can configure up to 4 CapSense buttons in hardware, eliminating the need for software tools, firmware development, and chip programming.

7.4.5 Evaluation Pods

PSoC EvalPods are pods that connect to the ICE In-Circuit Emulator (CY3215-DK kit) to allow debugging capability. They can also function as a standalone device without debugging capability. The EvalPod has a 28-pin DIP footprint on the bottom for easy connection to development kits or other hardware. The top of the EvalPod has prototyping headers for easy connection to the devices pins. The following are the evaluation pods available.

- CY3210-CY8C20x34 PSoC Evaluation Pod (EvalPod)
- CY3210-CY8C21x34 PSoC Evaluation Pod (EvalPod)
- CY3210-CY8C20x36/46/66 PSoC Evaluation Pod (EvalPod)
- CY3210-CY8C24x94 PSoC Evaluation Pod (EvalPod)

7.4.6 In-Circuit Emulation (ICE) Kits

The ICE pod provides the interconnection between the CY3215-DK In-Circuit Emulator via a flex cable and the target PSoC device in a prototype system or PCB via package-specific pod feet. Kit guide and Quick Start Guide for In Circuit Emulator (ICE) Development Kit are available here. Following are the Pods available.

- CY3250-21X34QFN In-Circuit Emulation (ICE) Pod Kit for Debugging QFN CY8C21x34 PSoC Devices
- CY3250-24x94QFN In-Circuit Emulation (ICE) Pod Kit for debugging QFN CY8C24x94 PSoC Devices
- CY3250-20246QFN In-Circuit Emulation (ICE) Pods for Debugging CY8C20236/46A PSoC Devices
- CY3250-20346QFN In-Circuit Emulation (ICE) Pod Kit for Debugging CY8C20336/346A CapSense PSoC Devices
- CY3250-20666QFN In-Circuit Emulation (ICE) Pod Kit for Debugging CY8C20636/646/666A CapSense PSoC Devices
- CY3250-20566 In-Circuit Emulation (ICE) Pod Kit for Debugging CY8C20536/546/566A CapSense PSoC Devices
- CY3250-20466QFN In-Circuit Emulation (ICE) Pod Kit for Debugging CY8C20436/46/66 CapSense PSoC Devices
- CY3250-20334QFN In-Circuit Emulation (ICE) Pods (2) for Debugging QFN CY8C20334 PSoC Devices

Replacement In-Circuit Emulation (ICE) Pods can be ordered here.

7.5 Demonstration Kit

The CY3235 - CapSense Proximity Detection Demonstration Kit allows quick and easy demonstration of a PSoC CapSense-enabled device (CY8C21434) to accurately sense the proximity of a hand or finger along the length of a wire antenna. The kit also includes the I^2C-USB Bridge, which allows hardware and software debugging of PSoC applications by seamlessly connecting PC's USB port to your application's I^2C interface.

7.6 I^2C-to-USB Bridge Kit

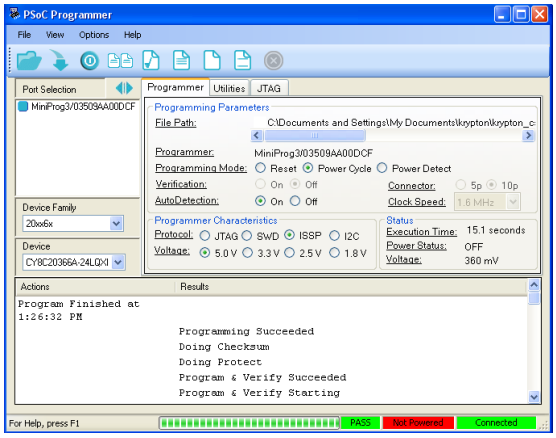
The CY3240-I2USB Kit allows you to test, tune, and debug hardware and software by bridging the USB port to I^2C. Populated with the CY8C24894 PSoC device, a wide variety of devices can be connected to the PC using this bridge including:

- EEPROMs
- Real Time Clocks
- ADC/DAC converters
- LCD displays
- Regulated DC/DC converters
- Port expanders
- Many other devices incorporating the I^2C interface.
- The number of devices that can be connected is constrained only by the I2C address limit and physical ability of the I^2C bus.

7.7 PSoC Programmer

PSoC Programmer is a flexible, integrated programming application for programming PSoC devices. PSoC Programmer can be used with PSoC Designer and PSoC Creator to program any design onto a PSoC device.

Figure 7-1. PSoC Programmer

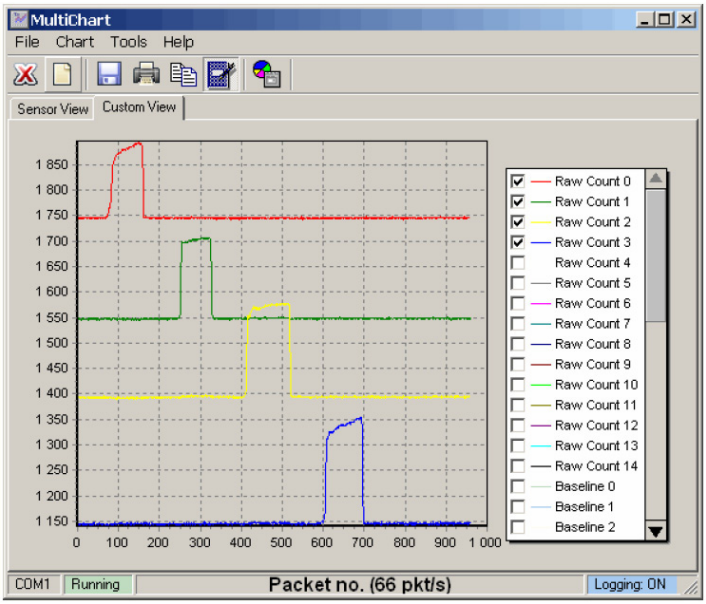


PSoC Programmer provides the user a hardware layer with API's to design specific applications utilizing the programmers and bridge devices. The PSoC Programmer hardware layer is fully detailed in the COM guide documentation as well as example code across the following languages: C#, C, Perl, and Python.

7.8 Multi-Chart

Multi-Chart is a simple PC tool for real-time CapSense data viewing and logging. The application allows you to view data from up to 48 sensors, save and print charts, and save data for later analysis in a spreadsheet.

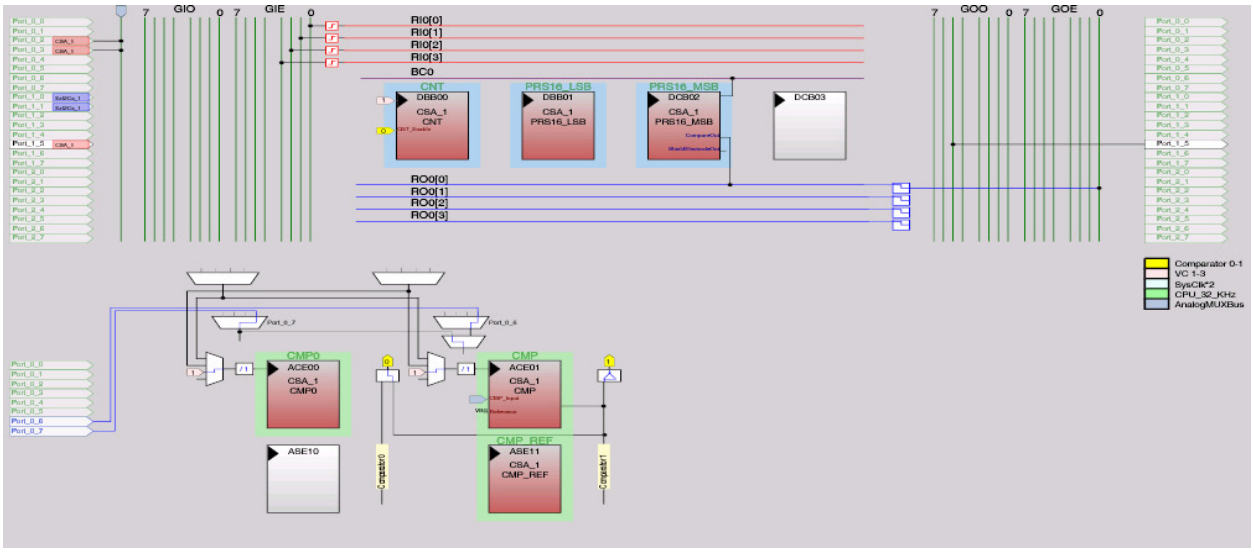
Figure 7-2. Multi-Chart User Interface



7.9 PSoC Designer

Cypress offers an exclusive Integrated Design Environment, PSoC Designer. With PSoC Designer you can configure analog and digital blocks, develop firmware, and tune your design. Applications are developed in a drag-and-drop design environment using a library of pre-characterized analog and digital functions, including CapSense. PSoC Designer comes with a built-in C compiler and an embedded programmer. A pro compiler is available for complex designs.

Figure 7-3. PSoC Designer Device Editor



7.10 Design Support

Cypress has a variety of support channels to ensure the success of your CapSense design.

- Knowledge Based Articles –Browse technical articles by product family or perform a search on various CapSense topics.
- Code Examples – Our vast collection of code examples will help get your design up and running fast.
- White Papers – Learn about advanced capacitive touch interface topics.
- Cypress Developer Community – Connect with the Cypress technical community and exchange information.
- Video Library – Quickly get up to speed with tutorial videos.
- Quality & Reliability – Cypress is committed to complete customer satisfaction. At our Quality website you can find reliability and product qualification reports.
- Technical Support – World class technical support is available on-line.